Oct. 26, 1965 E. H. MAHONEY 3,214,759

APPARATUS FOR PROVIDING LANE IDENTIFICATION IN HYPERBOLIC POSITION FINDING SYSTEMS

Filed April 19, 1962 3 Sheets-Sheet 1

Fig. 1

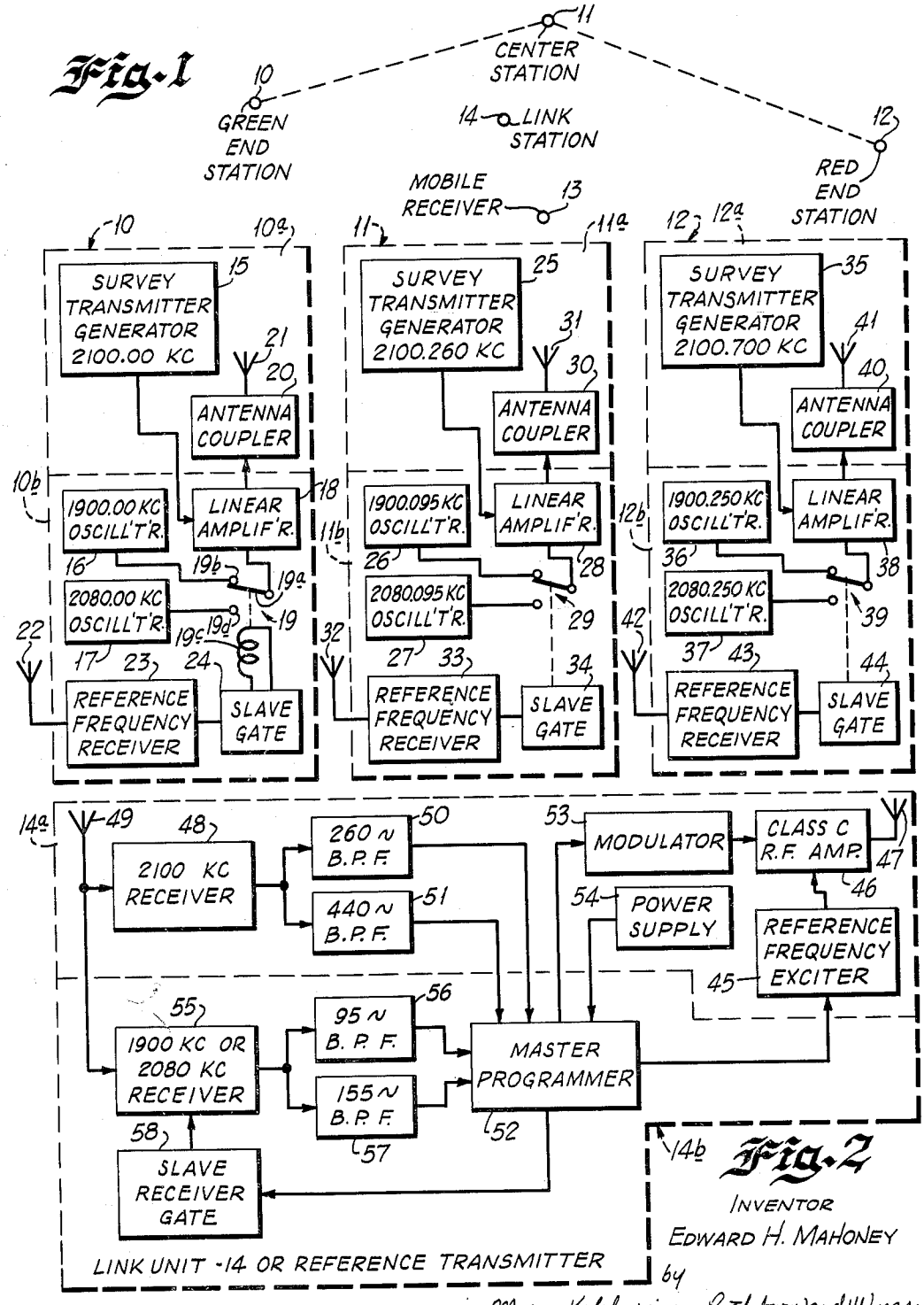


Fig. 2

INVENTOR
EDWARD H. MAHONEY

Mason, Kolehmainen, Rathburn and Wyss
ATTORNEYS

Oct. 26, 1965 E. H. MAHONEY 3,214,759
APPARATUS FOR PROVIDING LANE IDENTIFICATION
IN HYPERBOLIC POSITION FINDING SYSTEMS
Filed April 19, 1962 3 Sheets-Sheet 2

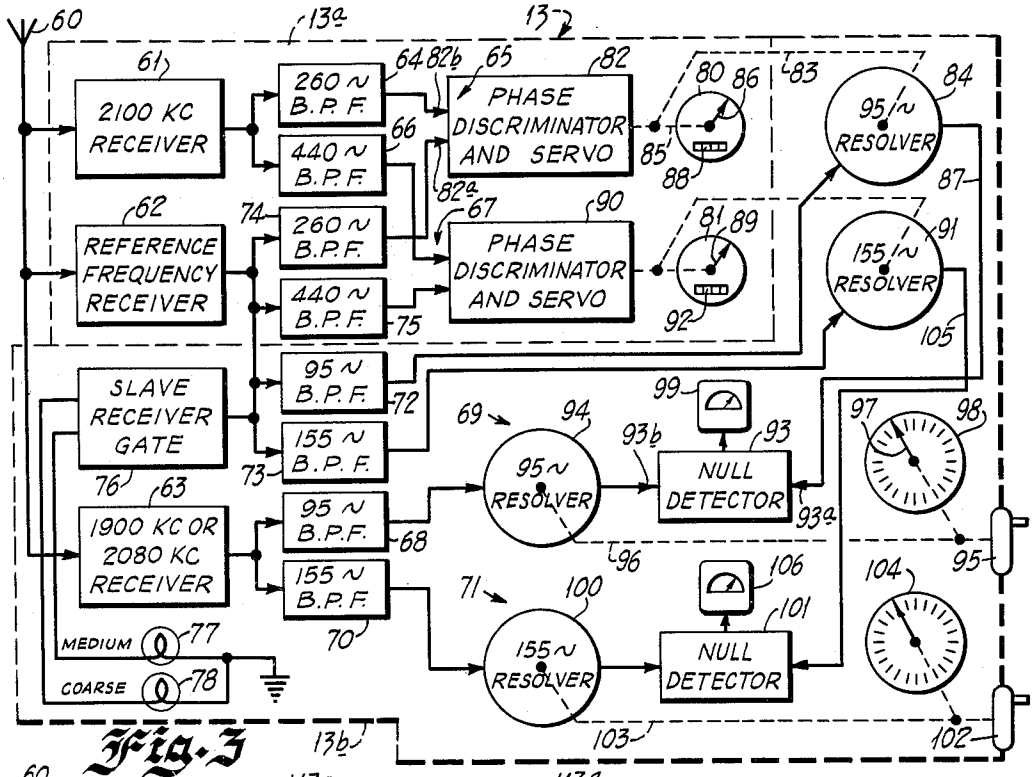


Fig. 3

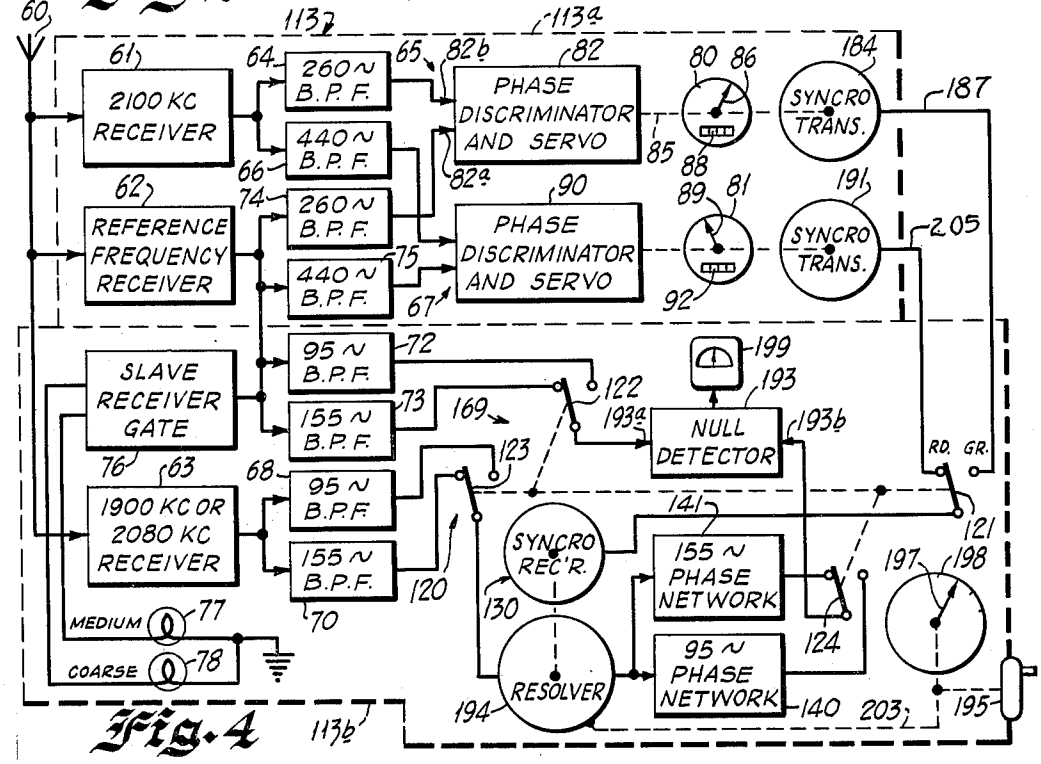


Fig. 4

Oct. 26, 1965 E. H. MAHONEY 3,214,759
APPARATUS FOR PROVIDING LANE IDENTIFICATION
IN HYPERBOLIC POSITION FINDING SYSTEMS
Filed April 19, 1962 3 Sheets-Sheet 3

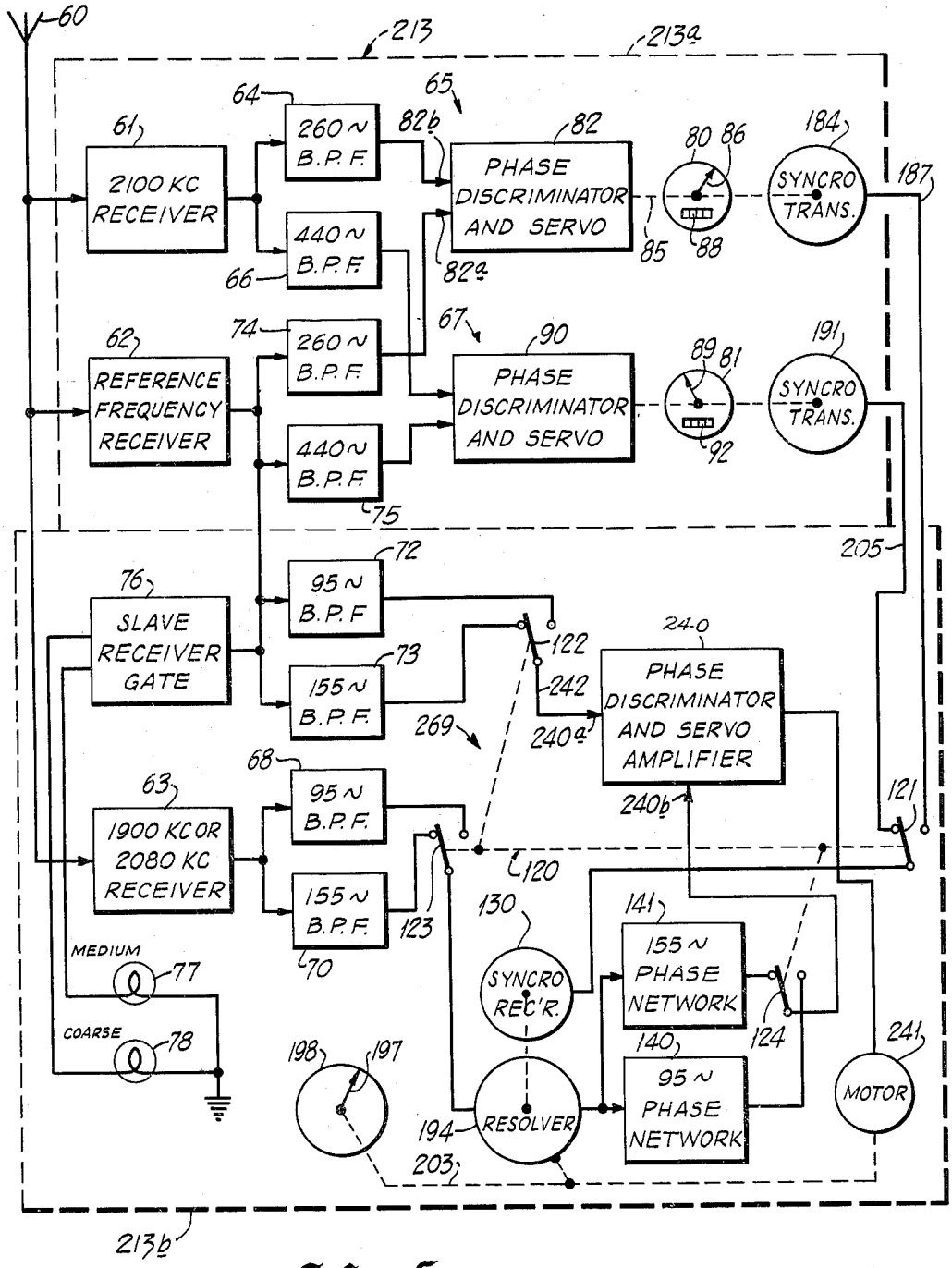


Fig. 5

United States Patent Office 3,214,759 Patented Oct. 26, 1965

3,214,759

APPARATUS FOR PROVIDING LANE IDENTIFICATION IN HYPERBOLIC POSITION FINDING SYSTEMS

Edward H. Mahoney, Tulsa, Okla., assignor to Seismograph Service Corporation, Tulsa, Okla., a corporation of Delaware

Filed Apr. 19, 1962, Ser. No. 188,692
21 Claims. (Cl. 343—105)

The present invention relates generally to radio position determining systems and is more particularly concerned with improvements in providing lane identification in radio position finding systems of the hyperbolic continuous wave type employing phase comparison in pairs of position indicating signals radiated from a plurality of spaced transmitting points to provide one or more indications from which the position of a mobile receiving point relative to the known locations of the transmitters may be determined very accurately. The invention is particularly concerned with a new and improved system of the above type including apparatus for modifying existing radio position finding systems to provide lane identification by utilizing a minimum amount of additional equpment and without discarding the equipment already in service.

In systems of the particular type referred to, the continuous waves radiated from each pair of transmitters bear a phase relationship at the mobile receiving unit which changes as a function of the changing position of the latter unit relative to the transmitting points. More specifically the waves radiated by each pair of transmitting units of the system are characterized by isophase lines which are hyperbolic in contour about the transmitting points as foci. With this system arrangement, the position of a receiving point relative to a pair of hyperbolic isophase lines may be determined by measuring the phase relationship between waves radiated from the pairs of transmitters. Since the point of location of the receiving point along the zone separating the two isophase lines is not indicated by such a phase measurement, it is desirable to employ at least three spaced transmitters, different pairs of which function to provide a grid-like pattern of intersecting hyperbolic isophase lines in order to obtain a position fix providing an absolute determination of the position of the receiving point.

In Honore Patent No. 2,148,267 a system is disclosed in which the waves radiated from each pair of transmitters are heterodyned at a fixed linked transmitting point and the difference frequency between the heterodyned waves is modulated as a reference signal on the carrier wave output of the link transmitter for radiation to the receiving point where the difference frequency component is detected and phase compared with the difference frequency signal derived by directly hererodyning the transmitted continuous waves arriving at the receiving point from the pair of transmitters. In this manner any phase shifts between the continuous waves radiated from the two transmitters are completely compensated so that the measured phase angle is truly representative of the location of the receiving point between the pair of isophase lines. In Hawkins Patent No. 2,513,316 an improved system is disclosed wherein a single reference transmitter is employed as a link transmitter for radiating all of the reference signals to the mobile receiving point, thereby reducing the number of signal channels required as well as the amount of equipment necessary to provide a complete system.

A particular problem encountered in the operation of continuous wave systems of the type disclosed in the Honore and Hawkins patents is that of eliminating ambiguity from the phase measurements which provide the desired position information. Thus, while the two phase measurements identify the position of the receiving station relative to two intersecting hyperbolic isophase lines, they do not identify the particular pair of lines to which the indications are related. This means that in operating the system, the geographic location of the receiving point must be known at the start of movement of the receiver relative to the transmitting stations and furthermore that the successive wavelengths or lanes traversed must be counted as the receiving station is moved relative to the grid-like pattern of hyperbolic lines. It also means that a mobile craft entering the radiation pattern of the transmitters cannot utilize the radiated signals to determine its position without employing auxiliary equipment to determine the approximate position of the craft relative to the signal transmitters.

One means employed heretofore for identifying the lanes or grids has been to provide an integrating counter mechanism which adds or subtracts a digit when the phase indicator undergoes a change of 360 degrees. Since a lane is crossed whenever such a 360 degree change occurs, the lanes are continuously identified by the integrating counter while the phase indicator provides information concerning the precise position of the mobile receiver within the lane identified. A system of this type, however, requires continuous, uninterrupted operation of the transmitting and receiving facilities even since relatively short periods of interrupted operation may result in the loss of one or more counts on the integrating counters if the mobile receiving unit moves during the period of interruption. Such interruptions might be caused by failure of the indicating, receiving or transmitting equipment for short periods of time, or in the alternative, by the presence of a weak signal area in the field pattern of the transmitting system. The presence of a weak signal area, which might be caused by local conditions adversely affecting radio wave propagation, renders the receiver insensitive to phase changes and, hence, the mobile unit may pass through a lane without at the same time adding or substracting a digit from the counting mechanism. As soon as the signal strength returns to normal or when the system is restored to normal operation, the phase indicator again provides accurate information concerning the location of the mobile craft but the integrating counters have, in the meantime, failed to record the lane change and as a result the actual position of the receiver cannot be determined. It would, of course, be desirable to provide a system for providing lane identification either independently of or in cooperation with the integrating counters so that accurate lane identification may be provided either initially when the mobile receiver enters the radiation pattern of the transmitters or at the completion of any period of interruption. The satisfaction of the latter desire therefore constitutes one of the principal objects of the present invention.

It has been found that in order to provide accurate position information and also in order to obtain frequency allocations from the Federal Communications Commission, the transmitters used in position finding systems of the type described above must operate at radio frequencies in the order of 1500 to 2000 kilocycles. When operating with such frequencies, one lane is only about 250 feet in the area along the base line extending between each pair of transmitters of the system. It has been suggested in several prior art patents, for example, in Palmer Patent Re. 24,891; Hawkins Patent No. 2,652,558; O'Brien Patent No. 2,598,290 and Hastings Patent No. 2,528,140, that ambiguity of the fine position indications can be resolved by, in effect, providing a second transmitting system operating at a

different frequency from the first to provide position indications in terms of the frequency difference between the two systems. However, as is pointed out in the Palmer patent, the difference frequency indications provided are ambiguous and the lanes of the "difference frequency" system are often so narrow that they do not cover any appreciable portion of the survey area. Thus, to provide coverage of a significant area, it is desirable to provide, in addition to the fine or accurate position indications and the medium indications of the "difference frequency" system, coarse indications for resolving ambiguity of the medium system. Prior systems for effecting this result have been characterized by several disadvantages. First, some systems have required an interruption in the transmission of signals from the transmitters of the fine system and a switchover to the transmission of the signals of the second system. The operator at the mobile unit is then called upon to read the new phase indication provided by the second system and to mentally compute the difference between the latter indication and the original one provided by the fine system. Obviously, this is a laborious and time consuming operation and one which is subject to considerable human error and it is, therefore, desirable to provide a system in which the "difference" indications are measured automatically and without resort to mental computation. Other systems have required the use of several radiating antennas at the same transmitting station or, in the alternative, three or more RF signals must be radiated simultaneously from the same antenna either in the form of three separate carrier waves or two carrier waves and one or more sidebands of modulation components. The use of separate antennas at each station is not practical in systems where the position measurement is accurate to within a few feet. Separation of the transmitting antennas by several feet at each station may destroy this accuracy. Moreover, even the use of separate antennas does not avoid the problem of high power radiation from one antenna to the other when these antennas are located very close together. Applicant has found that the radiation of more than two signals simultaneously from the same antenna creates loading problems which cannot easily be solved and, as a result, it would be desirable to provide a system for developing both fine, medium and coarse position indications without requiring the simultaneous radiation of more than two signals from the transmitting stations. The satisfaction of the latter desire constitutes another important object of the present invention.

A principal object of the present invention is to provide a new and improved apparatus for effecting lane identification in a hyperbolic continuous wave radio position finding system.

Another object of the present invention is to provide a new and improved transmitting system for use in radio position finding systems of the type described above.

The invention has for a further object the provision of a new and improved mobile receiving equipment for use in radio position finding systems of the type described above and including apparatus operative automatically to provide lane identification and without resort to mental computations.

It is a further object of the present invention to provide a system of the character described above wherein the equipment necessary for providing lane identification can be added to presently existing apparatus with a minimum amount of modification, thus economizing upon the installation cost and also preventing obsolescence of the existing apparatus.

The invention has for another object the provision of lane identification equipment of the character described which is simple in construction and, therefore, inexpensive to manufacture.

The invention, both as to its organization and manner

of operation, together with further objects and advantages will best be understood by reference to the following description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic diagram showing a typical arrangement of the transmitters of a three foci transmitting system characterized by the features of the present invention together with a mobile receiving unit whose position is to be determined;

FIG. 2 diagrammatically illustrates the equipment employed at the two end transmitting stations, the center station and the link or reference transmitting station of the transmitting system;

FIG. 3 is a diagrammatic representation of a mobile receiving unit for use with the transmitting system shown in FIG. 2 to provide a determination of the position of a mobile craft operating within the field pattern of the transmitting system;

FIG. 4 is a diagrammatic representation of another embodiment of a mobile receiving unit which may be used with the transmitting system shown in FIG. 2 to provide position information; and

FIG. 5 is a diagrammatic representation of a further embodiment of a mobile receiving unit for use with the transmitting system shown in FIG. 2.

Referring now to the drawings and more particularly to FIG. 1 thereof, the invention is there illustrated as embodied in a three foci hyperbolic, continuous wave system for providing position information at any number of mobile receiving units **13** (FIG. 3) which may be carried on vessels or vehicles operating within the transmission field of a plurality of spaced apart transmitters or transmitting units **10**, **11**, **12** and **14**. The transmitters **10**, **11** and **12** are preferably spaced apart approximately equal distances and are so positioned that an imaginary base line joining the points of location of the units **10** and **11** is angularly related to a similar base line joining the points of location of the units **11** and **12**. As a consequence, the transmitter or transmitting unit **11** may be considered to be the center transmitter while the transmitting units **10** and **12** may be referred to as the end transmitters with these units, for convenience, being respectively referred to as the Green End Station and the Red End Station in ensuing portions of this description. The transmitting unit **14** is spaced from all three of the units **10**, **11** and **12** and, since its function is to receive the signals radiated from the latter stations and to develop therefrom reference signals for radiation as modulation components, it is designated as the reference or link station. More specifically, the equipment provided at each of the transmitting stations **10**, **11** and **12** is effective to radiate continuously a first position indicating signal for use at the mobile receiving unit **13** in providing a fine or accurate position indication and, in addition, to radiate alternately second and third ambiguity resolution signals for use at the mobile receiving unit to provide medium and coarse position indications, respectively. The three fine position indicating signals continuously radiated from the stations **10**, **11** and **12** fall within a first frequency channel, which, for convenience, will be referred to hereinafter simply as the position indicating channel, while the two different ambiguity resolution signals alternately radiated fall within two different frequency channels, respectively, called hereinafter the first ambiguity resolution channel and the second ambiguity resolution channel, with each of the latter channels including one of the ambiguity resolution signals radiated from each of the three stations.

The reference station **14** is equipped to receive all of the position indicating and ambiguity resolution signals radiated from the transmitting stations **10**, **11** and **12** and to heterodyne these signals in pairs in order to develop reference signals for radiation as modulation components upon a carrier wave emitted from the ref-

erence station. The latter carrier wave lies within a fourth frequency channel which is different from the position indicating signal channel and also from the two ambiguity resolution signal channels. The carrier wave emitted from the reference station is modulated with reference signals derived from heterodyning the position indicating signals in pairs and is also alternately modulated with reference signals derived from heterodyning in pairs the signals of the two ambiguity resolution channels. The signal from the reference station **14** is also coded as described below to render each of the stations **10**, **11** and **12** alternately effective in synchronism to radiate the two ambiguity resolution signals and also to render each mobile receiving unit **13** effective to receive and use the particular set of ambiguity resolution signals being emitted from the transmitting stations **10**, **11** and **12**.

The mobile receiver **13** is equipped to receive all of the position indicating and ambiguity resolution signals as well as the coded reference station wave with its modulating reference signals. The mobile receiver responds to the signals of the position indicating channel and to the signal from the reference station by providing a first fine or accurate position indication representing the location of the mobile craft relative to a first family of hyperbolic, isophase lines having foci at the transmitting stations **10** and **11** and by providing a second fine or accurate position indication representing the location of the mobile craft relative to a second family of hyperbolic, isophase lines having foci at the transmitting stations **11** and **12**. The mobile receiver **13** is also equipped to count the lanes of the two families of isophase lines traversed by the mobile craft. During the period when the ambiguity resolution signals of the first ambiguity resolution channel are being received this receiver is effective to provide automatically a medium position indication representing the location of the mobile craft relative to hyperbolic isophase lines having foci at the transmitting stations **10** and **11** and to provide another medium position indication representing the location of the craft relative to another set of hyperbolic lines having foci at the stations **11** and **12**. During the period when the signals of the second ambiguity resolution channel are being received, the receiver **13** provides automatically a coarse position indication representing the location of the mobile craft relative to widely spaced hyperbolic isophase lines having foci at the transmitting stations **10** and **11** and also provides a second coarse position indication representing the location of the craft relative to a set of widely spaced isophase lines having foci at the stations **11** and **12**.

Briefly considered, the equipment provided at the Green End Transmitting Station **10** comprises three different oscillators or wave signal generators **15**, **16** and **17** of conventional construction which are respectively adapted to develop signals having different frequencies. While the particular frequencies used in the system are unimportant, the oscillators have been assigned specific frequenciese to facilitate the description. Thus, the oscillator or generator **15** develops signals having a frequency of 2100.00 kilocycles which are continuously supplied to linear amplifier **18** of the type described in detail in United States Patent No. 2,872,676 assigned to the same assignee as the present invention. Oscillators **16** and **17** respectively develop signals of 1900.00 and 2080.00 kilocycles which are alternately supplied through the contacts of a switching relay **19** to the linear power amplifier **18**. The latter amplifier functions in the manner described in the above-identified Patent No. 2,872,676 to combine the two input signals linearly in order to develop an output signal free of intermodulation components and this output signal is supplied through an antenna coupler **20** for emission from a radiating antenna **21**. The relay is effective to connect the output of the oscillators **16** and **17** one at a time to the input of the linear power amplifier **18**. Thus, with the relay **19** deenergized, its movable arm or pole **19***a* engages a fixed contact **19***b* to deliver the signals from the oscillator **16** to the power amplifier. When the relay **19** is energized by supplying current to its operating coil **19***c* in a manner described hereafter, the pole **19***a* is drawn into engagement with a fixed contact **19***d* to deliver signals from the oscillator **17** to the amplifier **18**. The energization of the relay **19** is controlled by coding the signal from the reference station **14**, for example, by interrupting the transmission of the carrier wave or, in the alternative, by modulating the latter wave with a tone switching signal of predetermined audio frequency. In the ensuing description, it will be assumed that the coding of the signal from the reference station is accomplished by interrupting the transmission for a brief period. To control the operation of the relay **19**, the equipment provided at the Green End Station **10** includes a receiving antenna **22** connected through an antenna coupler (not shown) to a conventional superheterodyne receiver **23** which is tuned to receive the carrier wave radiated from the reference station. The receiver **23** drives a slave exciter gate circuit **24** which includes a detector circuit for determining the presence or absence of signals from the reference station. It may comprise a circuit for developing a control signal wherever the carrier wave radiation from the reference station is terminated. This control signal is passed to a timing circuit which drives the relay coil **19***c* to energize the relay. The timing circuit maintains the relay **19** energized both during the off period of the reference station and for a predetermined interval thereafter. To facilitate the description, let it be assumed that the reference station is so programmed that it is off for a period of ten seconds and is then effective to radiate its carrier wave for a period of one minute and fifty seconds, thus providing a two minute cycle. The relay **19** is energized both for the ten second off period and for a predetermined interval of fifty seconds thereafter as controlled by the timing circuit in the slave gate **24**. At the completion of the fifty second interval, the reference station will be radiating its carrier wave and the slave gate **24** will supply no energizing signal for the relay **19**. The latter relay then remains deenergized for the remaining one minute of the cycle to supply the output of the oscillator **16** to the linear amplifier **18**. Thus, it will be observed that the amplifier **18** is alternately excited by 2080.00 and 1900.00 kilocycle signals respectively supplied from the oscillators **16** and **17** with each signal being supplied for a one minute period. These two signals are thus alternately radiated from the antenna **21** while the 2100.00 kilocycle signal from the oscillator **15** is continuously radiated from this antenna.

In accordance wth an important feature of the present invention the equipment for providing lane identification is adapted to be added to presently existing equipment in which lane identification is effected solely by the aforementioned integrating connectors. The modifications necessary to add the lane identification facilities of the present invention are very slight. Thus, the fine position indications provided by the signals continuously radiated from the stations **10**, **11** and **12** and by the reference signal radiation from the link unit **14** are obtained by equipment which is very similar to the systems shown in U.S. Patent No. 2,513,316. Since a number of systems of the latter type are presently in operation, it is desirable to incorporate the lane identification therein while preserving the original equipment to as great a degree as possible. The existing equipment at the four transmitting stations **10**, **11**, **12** and **14** has been shown within the broken line rectangles **10***a*, **11***a*, **12***a* and **14***a*, respectively, while the equipment which must be added for lane identification has been shown within the broken line rectangles **10***b*, **11***b*, **12***b* and **14***b*, respectively. Similarly, the equipment previously used at the mobile receiving unit **13** is shown within the broken lines **13***a* while the equipment to be added according to the present invention is shown

within the broken lines 13*b*. It will be observed that at the transmitters 10, 11, 12 and 14 almost all of the original equipment including the oscillators, the antennas, the couplers, the modulators and filters at the station 14 etc. has been preserved for use in the system of the present invention. The entire original mobile receiving unit has also been used thus avoiding the necessity for completely discarding all such receivers presently in use.

The equipment provided at the Center Station 11 is identical to that at the Green End Station 10 except for the frequencies of the oscillators or wave signal generators. Thus, the Center Station is provided with three RF oscillators 25, 26 and 27 respectively developing signals having frequencies of 2100.260, 1900.095 and 2080.95 kilocycles. Here again, the output of the oscillator 25 is continuously applied to a linear power amplifier 28 like the amplifier 18 referred to above, while the outputs of the oscillators 26 and 27 are alternately supplied to the linear amplifier 28 through the contacts of a relay 29 which is identical to the relay 19 previously described. The linear amplifier 28 combines the applied input signals linearly and supplies its output signals through an antenna coupler 30 for radiation from an emitting antenna 31. The operation of the relay 29 is controlled by the coded reference station signals in exactly the same manner as described above and, as a result the Center Station includes a receiving antenna 32 coupled through an antenna coupler (not shown) to a conventional superheterodyne receiver 33. The latter receiver is again tuned to accept the carrier wave radiated from the reference station 14 and is sufficiently selective to reject the signals falling within the position indicating signal channel and also those falling within the two ambiguity resolution signals. The output of the receiver 33 is supplied to an exciter slave gate circuit 34 exactly like the gate 24 previously described so that the relay 29 is energized in the absence of the carrier wave from the reference station and for a predetermined interval (fifty seconds for example) after the radiation of the carrier wave is resumed. The relay 29 is, of course, deenergized at the completion of the fifty second delay interval. When deenergized, the relay 29 supplies signals from the oscillator 26 to the linear amplifier 28 and, when energized, it supplies signals to the amplifier from the oscillator 27. Thus, the amplier 28 alternately supplies the 1900.095 and 2080.095 kilocycle signals from the oscillators 26 and 27 to the antenna 31 so that these two signals are radiated alternately for one minute periods and, at the same time, the amplifier 28 supplies continuously the 2100.260 kilocycle signal from the oscillator 25 to the antenna 31 so that this signal is continuously radiated.

The equipment provided at the Red End Station 12 is identical to that provided at the Green End Station 10 and at the Center Station 11 except for the operating frequencies of the three oscillators. Thus, the equipment at the Red End Station 12 includes three oscillators 35, 36 and 37 for developing signals respectively having frequencies of 2100.700, 1900.250 and 2080.500 kilocycles. The output of the oscillator 35 is continuously supplied to a linear power amplifier 38 identical to the amplifier 18 described above while the oscillators 36 and 37 are connected alternately through a relay 39 to the power amplifier 38 in a manner which will be obvious in view of the foregoing description. The combined signal output from the power amplifier 38 is supplied through an antenna coupler circuit 40 to an emitting or radiating antenna 41. To provide signals for controlling the operation of the relay 39, the Red End Station includes a receiving antenna 42 connected to a conventional superheterodyne receiver 43. The latter receiver is tuned to accept the carrier wave radiated from the reference station 14 and to reject the remaining signals in the different frequency channels of the transmitting system. The receiver 43 drives a slave exciter gate 44 like the gate 24 described above to energize the relay 39 in the absence of the carrier wave from the reference station and for a fixed interval, i.e., fifty seconds after radiation of this wave has been resumed. At the completion of the fixed delay interval, the slave gate 44 is effective to deenergize the relay. The relay 39 functions to connect the amplifier 38 alternately to the oscillators 36 and 37 in a manner which will be obvious from the foregoing description so that the 1900.250 and 2080.250 kilocycle signals from the oscillators 36 and 37 are radiated alternately from the antenna 41 for one minute periods while, at the same time, the 2100.700 kilocycle signal from the oscillator 35 is radiated continuously throughout both such periods.

In view of the foregoing description, it will be recognized that the three signals developed by the oscillators 15, 25 and 35 fall within the first or position indicating frequency channel. All three of these signals are radiated simultaneously and continuously. The signals developed by the oscillators 16, 26 and 36 fall within the first ambiguity resolution signal channel and are radiated simultaneously with each other for one minute periods. Similarly, the signals developed by the oscillators 17, 27 and 37 fall within the second ambiguity resolution signal channel and are radiated simultaneously with each other but alternately with signals of the first ambiguity resolution channel and for one minute periods beginning with the interruption of carrier wave radiation from the reference station 14 and continuing for fifty seconds after such radiation is resumed. While, as was previously indicated, the particular frequencies are unimportant, in order to provide effective ambiguity resolution using equipment having the usual tolerances or errors, the frequency difference between the signals of the first or position indicating signal channel and those of the first ambiguity resolution channel should be equal to about one tenth (0.1) of the frequency of the position indicating channel while the frequency difference between the signals of the second ambiguity resolution channel and those of the position indicating channel should be about one hundredth (.01) of the position indicating channel frequency.

Considering next the equipment provided at the reference station 14, it will be observed that this equipment includes an RF oscillator or exciter 45 for developing a carrier wave signal having a frequency FR which as was indicated above falls in a frequency channel distinguishable from the other three channels. The output of the oscillator 45 is applied to a conventional class C RF power amplifier 46 which has its output signals supplied through an antenna coupler circuit (not shown) to an emitting or radiating antenna 47. As was previously indicated, the carrier wave developed by the oscillator 45 is adapted to be modulated with reference signals derived from heterodyning the signals received from the stations 10, 11 and 12. To develop these reference signals, the reference station 14 includes a conventional superheterodyne receiver 48 having an input or RF section receiving signals from a receiving antenna 49 through an antenna coupler circuit (not shown). This RF section is tuned to accept the signals in the first or position indicating channel but to reject signals in the two ambiguity resolution signal channels. The receiver 48 is effective to heterodyne in pairs the three signals of the first channel to develop the audio frequency differences or beats therebetween. Thus, the receiver 48 continuously produces an output consisting of a first audio difference signal of 260 cycles derived from heterodyning the 2100.00 and 2100.260 kilocycle signals received from the transmitters 10 and 11, a second audio difference signal of 440 cycles derived from heterodyning the 2100.260 and 2100.700 kilocycle signals received from the transmitting units 11 and 12 and a third audio difference frequency signal of 700 cycles derived from heterodyning the 2100.00 and 2100.700 kilocycle signals respectively received from the transmitting units 10 and 12. These three difference frequency signals are supplied to a pair of bandpass filters

50 and 51 respectively tuned to pass the 260 cycle and 440 cycle signals. The 700 cycle difference signal is, of course, rejected by both of the filters 50 and 51 and, hence, has no effect upon the operation of the reference station. The two difference signals passed by the filters 50 and 51 are applied to a master programmer and linear mixer circuit 52 which combines these signals linearly and without heterodyning them. The circuit 52 has its output connected to a modulator 53 which is effective during most of the cycle to amplitude modulate the carrier wave signal F_R developed by the oscillator 45 with the 260 and 440 cycle reference signals.

The master programmer circuit 52 performs several functions in addition to the mixing of the signals passed by the filters 50 and 51. Thus, it also serves to code the transmissions from the reference station 14 to control the alternate radiation of signals in the two ambiguity resolution channels from the transmitting stations 10, 11 and 12. As was previously indicated this coding could take the form of tone switching signals modulated upon the carrier wave F_R but in the form being described it is accomplished by a coded interruption of transmission of the wave F_R from the station 14. The transmission may be interrupted in any suitable manner, as for example, by supplying power from a power supply 54 to the exciter 45 through a motor driven switch (not shown) in the master programmer circuit. The latter switch, as is well known in this art, may include insulating and conducting sections suitably arranged to supply power to the exciter 45 only during those periods when transmission of the carrier wave F_R is desired. As was indicated above, this switch is constructed and arranged to interrupt radiation of the carrier wave F_R for a ten second period of each two minute cycle so that the carrier wave is, of course, radiated for one minute and fifty seconds of each cycle during which time the wave is continuously modulated by both of the reference signals from the filters 50 and 51. At the same time power is supplied from the motor driven switch to a slave gate circuit 58 for controlling the operation of a receiver 55. More specifically, the receiver 55 must be operated in synchronism with the coding of the reference station so that it is alternately effective to receive signals in the first ambiguity resolution channel (i.e. in the vicinity of 1900 kilocycles) when the transmitters 10, 11, and 12 are radiating such signals and to receive signals in the second ambiguity resolution channel (in the vicinity of 2080 kilocycles) when the later signals are being radiated. To this end, the slave gate 58 includes means (such as a relay) effective during the ten second interruption period of the motor driven switch in the master programmer circuit 52 and for fifty second period thereafter to alter the frequency of the local oscillator in the superheterodyne receiver 55. The local oscillator develops a signal 455 kilocycles higher than the incoming signal so that the local oscillator output and the receiver signals can be mixed to produce the usual 455 kilocycle intermediate frequency. Thus, when the transmitters 10, 11 and 12 are radiating the signal of the second channel the local oscillator signal should be 1900 + 455 or 2355 kilocycles and when these transmitters are radiating signals in the third channel the local oscillator signal should be 2080 + 455 or 2535 kilocycles. This can be accomplished by providing two different local oscillators which are rendered alternately effective in synchronism with the coding of the reference station signal by supplying power from the power supply 54 through the switch in the master programmer circuit 52 to the gate 58. The gate 58 renders the two local oscillators alternately effective for one minute periods.

When the transmitting stations 10, 11 and 12 are effective to radiate simultaneously the signals of the first ambiquity resolution channel in the vicinity of 1900 kilocycles, the receiver 55 accepts these three signals and develops a first difference frequency of 95 cycles as a result of heterodyning the 1900.000 and 1900.095 kilocycle signals respectively radiated from the stations 10 and 11, a second difference frequency of 155 cycles derived from heterodyning the 1900.095 and 1900.250 kilocycle signals respectively radiated from the stations 11 and 12 and a third difference frequency of 250 cycles derived from heterodyning the 1900.000 and 1900.250 kilocycle signals respectively radiated from the stations 10 and 12. During the period when the transmitting stations 10, 11 and 12 are effective to radiate simultaneously the signals of the second ambiguity resolution channel in the vicinity of 2080 kilocycles, the receiver 55 heterodynes these three signals in pairs to develop a difference frequency of 95 cycles as a result of heterodyning the 2080.000 and 2080.095 kilocycle signals respectively radiated from the stations 10 and 11, another difference frequency of 155 cycles derived from heterodyning the 2080.095 and 2080.250 kilocycle signals respectively radiated from the stations 11 and 12, and another difference frequency of 250 cycles derived from heterodyning the 2080.00 and 2080.250 kilocycle signals respectively radiated from the stations 10 and 12. Thus, the three difference signals developed by the receiver 55 when the signals of the first ambiguity resolution channel are being received from the stations 10, 11 and 12 have the same frequencies as the three difference signals developed when the signals of the second ambiguity resolution channel are being received. This is, of course, accomplished by proper selection of frequencies of the oscillators 16, 17, 26, 27, 36 and 37. The three difference frequencies developed by the receiver 55 during both periods of operation are applied to a pair of conventional bandpass filters 56 and 57 for respectively passing the 95 and 155 cycle difference frequencies. The 250 cycle difference frequency is rejected by both of the filters 56 and 57 and, hence, has no effect on the operation of the reference station. The 95 and 155 cycle difference frequencies passed by the filters 56 and 57 are applied to the linear mixer portion of the master programmer circuit where they are combined with the 260 and 440 cycle difference frequencies from the filters 50 and 51. All of the difference frequencies supplied to the master programmer are combined linearly without generating intermodulation components and the combined signals are applied to the amplitude modulator 53 which, of course, modulates the difference frequencies upon the carrier wave F_R developed by the oscillator 45 throughout the one minute and fifty second period when the latter wave is being developed. It will be observed that the selection of frequencies so that the difference frequency between the signals developed by the oscillators 16 and 26 is equal to the difference between the signals developed by the oscillators 17 and 27 and, further that the difference between the signals developed by the oscillators 26 and 36 is equal to the difference between the signals produced by the oscillators 27 and 37, simplifies the equipment used at the reference station since only one receiver and one pair of filters is required to receive all of these signals. In view of the foregoing description, it will be recognized that the reference station 14 is effective to radiate a periodically interrupted carrier wave F_R which, throughout its period of transmission, is continuously modulated by a first pair of 260 and 440 cycle reference signals and which is, at the same time, alternately modulated by second and third pairs of reference signals with each pair of signals being made of a 95 cycle and a 155 cycle audio signal. The two 95 cycle signals and the two 155 cycle signals may differ from each other in phase due to the fact that they are derived from heterodyning different pairs of signals.

As is shown in FIG. 3 of the drawings, the equipment provided at the mobile receiving unit 13 comprises a single receiving antenna 60 connected to an antenna coupler circuit (not shown) to supply input signals for three conventional superheterodyne receivers 61, 62 and 63. The receiver 61 has its RF circuits tuned to ac-

cept the signals of the position indicating channel but to reject the signals of the three remaining channels in the system. The signal input circuits of the receiver **62**, on the other hand, are tuned to accept the carrier wave F_R and its modulation components but to reject the remaining signals of the other three channels. The receiver **63** has its local oscillator frequency shifted in synchronism with the coding of the reference station signal in a manner somewhat similar to the receiver **55** employed at the reference station **14**. The signal input circuits of the receiver **63** are designed to accept both of the ambiguity resolution signal channels and to reject both the carrier wave F_R, and the signals of the position indicating channel in the vicinity of 2100 kilocycles. The receiver **61** is continuously effective to heterodyne in pairs the signals of the position indicating channel to develop the difference frequencies therebetween. Thus, the signals received from the transmitting stations **10** and **11** are heterodyned to develop a 260 cycle beat or difference frequency signal which is passed through a bandpass filter **64** to a phase comparison or indicating circuit **65** described more fully hereinafter. The 440 cycle difference signal developed by heterodyning the waves received from the stations **11** and **12** is passed through a bandpass filter **66** to a second phase comparison or indicating circuit **67** which is similar to the phase comparison circuit **65**. The 700 cycle difference frequency developed by heterodyning the signals received from the two end stations **10** and **12** is, of course, rejected by both of the filters **64** and **66** and, hence, has no effect upon the operation of the equipment at the mobile receiving unit **13**.

The receiver **63** is broadly tuned to accept the signals in both of the ambiguity resolution signal channels, that is, signals in the vicinity of 1900 and 2080 kilocycles. Since the signals in only one of these ambiguity resolution channels are radiated during any particular interval, the signals of both channels do not, of course, arrive at the receiver **63** simultaneously. The three signals of each channel arriving at the receiver **63** at any one time are heterodyned in pairs to develop the 95 cycle difference signal between the signals radiated from the stations **10** and **11** and the 155 cycle difference frequency between the signals received from the stations **11** and **12**. The 95 cycle difference signals are passed through a bandpass filter **68** to a phase comparison circuit **69** for the purpose of providing ambiguity resolution in a manner which will become evident as the description proceeds. The 155 cycle difference signals are passed through a bandpass filter **70** to a phase comparison circuit **71** in order to provide ambiguity resolution. The 250 cycle difference between the signals arriving from the end stations **10** and **12** is also developed by the receiver **63** but, here again, this signal has no effect on the operation because it is rejected by both of the filters **68** and **70**.

The reference receiver **62** is tuned to accept the carrier wave F_R radiated from the reference station **14** and to reject the other three frequency channels utilized in the system. The receiver **62** detects the modulation components appearing upon the carrier wave radiated by the reference station **14** and develops these modulation components at its output terminals. Both of the 95 cycle reference signals alternately appearing on the wave F_R are passed through a bandpass filter **72** to the phase comparison circuit **65** while both of the alternately appearing 155 cycle reference signals are passed through a filter **73** to the phase comparison circuit **67**. The 260 and 440 cycle reference signals are respectively passed through bandpass filters **74** and **75** to the phase comparison circuits **65** and **67**. The coded or periodically interrupted reference signal F_R is also used to drive a slave receiver gate circuit **76** which may include a timing circuit like that used at the stations **10, 11** and **12** for performing the function of conditioning the receiver **63** to correspond with the ambiguity resolution channel being radiated by the stations **10, 11** and **12**. This is accomplished by connecting to the receiver **63** the proper local oscillator for the frequency channel being received in a manner which will be obvious in view of the foregoing description. In addition, the gate circuit **76** supplies current to an indicating light **77** whenever the signals of the first ambiguity resolution channel are being received and supplies current to an indicating light **78** whenever the signals of the second ambiguity resolution channel are being received. The illumination of the lights **77** and **78** informs the operator at the mobile receiving unit as to whether a medium or coarse ambiguity resolution measurement is being made.

The phase comparison circuit **65** may be referred to as the Green comparison circuit since it utilizes the signals supplied from the receivers **61** and **62** to provide on an indicating device or meter **80** a fine position indication representative of the location of the mobile receiving unit **13** relative to the Green family of closely spaced, hyperbolic, isophase lines having foci at the Center Station **11** and the Green End Station **10**. The phase comparison circuit **67** may be referred to as the Red circuit because it provides on a meter **81** a similar fine position indication representative of the location of the mobile receiving unit relative to closely spaced, hyperbolic, isophase lines of the Red family having foci at the Center Station **11** and the Red End Station **12**. Only the phase comparison circuit **65** need be described in detail since the circuit **67** is identical thereto and performs in a manner which will become obvious after the description of the circuit **65** has been completed. The phase comparison circuit **65** is generally similar to that described and claimed in United States Patent No. 2,551,211 granted to James E. Hawkins and Beverly W. Koeppel and assigned to the same assignee as the present invention. Reference to the latter patent may be taken for a more detailed description of the operation of the individual components of the indicating equipment. Thus, the Green phase comparison circuit **65** comprises a phase discriminator and servo-circuit **82** including a servo-motor (not separately shown) having its output shaft connected through reduction gearing (also not separately shown) to drive the rotor of a control transformer or resolver forming part of the circuit **82**. The rotor of the latter resolver is, in turn, connected, as indicated by the broken line **85**, to drive a rotatable pointer **86** which forms part of the indicator **80**. The pointer rotates over a circular face or scale having suitable graduations around its periphery to permit the indication of the phase relationship between the two audio frequency signals applied to the input terminals of the phase comparison circuit **65**. One set of signal input terminals **82***a* of the phase discriminator and amplifier circuit **82** is supplied with 260 cycle reference signals passed through the bandpass filter **74** while a second set of signal input terminals **82***b* of this phase discriminator is excited by the 260 cycle beat or heterodyne signals passed through the filter **64**. The circuit **82** operates in a manner described in Patent No. 2,551,211 to compare the phases of the two 260 cycle signals supplied to its two sets of input terminals, and to develop a D.C. control signal whenever the compared signals differ in phase. The polarity of the D.C. control signal depends upon the direction of the deviation while the amplitude of the signal, of course, depends upon the amount of the phase difference. This control signal it utilized in a manner which will be apparent to those skilled in this art to control the direction of drive of the servo-motor and the pointer **86**.

As is described in the above-identified Patent No. 2,551,211, the control transformer or resolver of the circuit **82** includes a rotor winding and a pair of stator windings, the latter being displaced mechanically 90 degrees and being excited with excitation signals displaced 90 degrees in phase. The circuit is in the form of a balanced servo-loop and the pointer **86** cooperates with the graduated scale on the face of the indicator **80** to indicate the position of the mobile receiving unit **13** along one of the

hyperbolic lines of the Green family. The indicating scale on the face provides a continuous reading from zero degrees to 360 degrees and, hence, one complete revolution of the pointer **86** during movement of the mobile craft carrying the receiving unit **13** indicates that a lane of the Green family has been traversed. The lanes of the Green family to which the indications on the indicator **80** pertain are spaced apart along the base line between the stations **10** and **11** by a distance equal to one-half wave length of the 2100 kilocycle position indicating channel and, since these lanes diverge on both sides of the base line, a greater distance must be traversed in other areas to cause a complete revolution of the pointer **86**. The latter pointer is connected through mechanism not illustrated in the drawings to drive a set of integrating counters **88** which register the number of complete 360 degree revolutions of the pointer **86**, thus providing a count to identify the Green lane within which the mobile receiving unit is located.

The phase comparison circuit **67** includes a phase discriminator and servo-circuit **90** having a resolver therein for driving a pointer **89** of the indicator **81** to identify the position of the mobile craft along one of the hyperbolic isophase lines of the Red family having foci at the stations **11** and **12** in order to provide a fine or accurate position indication. A set of integrating counters **92** count the number of lanes of the Red family traversed to identify the particular Red lane within which the mobile craft is located. Thus, in operation if the mobile receiving unit **13** enters the field of radiation of the transmitting units **11**, **12**, **13** and **14** at a known geographic location, the indicators **80** and **81** and their associated counters **88** and **92** may be initially set until the readings correspond to the known geographic location. The pointers of the indicators are driven in response to the received signals when the mobile craft is moved from the known geographic location.

As thus far described, the indicating equipment is similar to that disclosed in the above-identified Patent No. 2,551,211 and, hence, as long as the system remains in continuous operation following the start of the mobile receiving unit at the known geographic location, the pointers **80** and **81** and the revolution counters **88** and **92** function continuously to provide position information. To provide ambiguity resolution of the fine position indications of the Green system, in accordance with an important feature of the present invention, the rotor of the resolver in the circuit **82** is mechanically connected as indicated by the broken line **83** to drive the rotor of another resolver **84** while the rotor of the resolver in the circuit **90** is similarly connected to drive the rotor of a resolver **91**. The stator windings of the resolver **84** are excited by 95 cycle signals which are displaced 90 degrees in phase as, for example, by using a phase shifting network not illustrated in the drawings, but forming part of the resolver circuit. The voltages induced in the rotor winding of the resolver **84** have a phase which depends both upon the phase of the 95 cycle stator excitation signals and upon the position of the rotor winding relative to the fixed stator windings. Thus, the 95 cycle output voltage from the resolver **84** derived from the rotor winding is supplied via a conductor **87** to the circuit **69** but this signal is phase shifted in accordance with the position of the rotor which is, in turn, a function of the phase relationship between the 260 cycle signals applied to the terminals **82***a* and **82***b*. The phase shifted 95 cycle signal appearing on the conductor **87** is applied to one set of input terminals **93***a* of a conventional galvanometer type null detector **93** which has its other input terminals **93***b* excited by the 95 cycle beat signals supplied to the circuit **69** from the band-pass filter **68**. More specifically, the 95 cycle signals from the filter **68** are used to develop quadrature components for application to the stator windings of a resolver **94** identical to the device **84** described above. The output signals from the rotor winding of the resolver **94** are applied directly to the terminals **93***b*. The rotor of the resolver **94** is adapted to be turned manually by a hand operated crank **95** connected mechanically to the rotor through a connection represented by the broken line **96**. The latter mechanical connection drives directly an indicator or pointer **97** movable over the face of a graduated scale or plate **98** for the purpose of indicating an angular position of the rotor of the resolver **94**. When the two 95 cycle signals applied to the two sets of input terminals **93***a* and **93***b* are in phase the null detector circuit **93** provides a null or zero output to an associated galvanometer or meter **99**. The null detector **93** is a discriminator type circuit for developing a D.C. control signal when the two input signals are not in phase, the magnitude of the control signal being a function of the amount of phase deviation and the polarity being a function of the direction of deviation.

Except for the frequencies of the audio signals, the lane identification circuit **71** associated with the Red system is identical to that for the Green system described above. Thus, the circuit **71** includes a resolver **100** having its stator windings excited by the 155 cycle signal from the filter **70** and having its rotor winding connected to one side of a null detector **101**. The rotor of the resolver **100** is turned by a hand crank **102** acting through a mechanical connection **103** which also drives an indicator or fractional lane counter **104**. The null detector **101** is also excited by 155 cycle signals derived from the rotor winding of a resolver **91** having its stator windings energized by 155 cycle reference signals from the filter **73**. Since the rotor of the resolver **91** is driven by the Red comparison circuit **67**, the output signal appearing on conductor **105** is phase shifted by an amount corresponding to the phase relationship between the 440 cycle signals passed by the filters **66** and **75**. As before, the null detector **101** compares the phases of the 155 cycle signals supplied to its opposed input terminals and, if these two signals are not in phase, develops a D.C. output for driving a galvanometer or meter **106**.

The circuits **69** and **71** are adapted to provide coarse and medium position indications for checking the accuracy of the integrating counters **88** and **92**. Actually, if the system functions perfectly and without interruption the counters **88** and **92** will provide accurate lane counts for both the Red and Green systems but, in the event of an equipment failure either at one or more of the transmitting stations or at the mobile receiving unit, the signal drive to either or both of the phase comparison circuits **65** or **67** is interrupted and, as a consequence, the pointers and integrating counters of the non-excited circuit or circuits will maintain the positions occupied just prior to the interruption. The positions of the movable pointer or pointers and the associated counter or counters will thus remain fixed despite movement of the mobile craft within the radiation field of the transmitters during the interruption period and, hence, when the source of trouble has been located and repaired and when the system is restored to normal operation, the indications provided will no longer be accurate. More specifically, when the system operation is restored, the reference signals and the beat signals passed by the filters **64**, **66**, **74** and **75** will immediately excite the phase discriminator and servo-circuits **82** and **90** to drive the servo-motor in each circuit until the servo-loop is balanced whereupon the pointers **86** and **89** identify intersecting hyperbolic, isophase lines of the Green and Red families passing through the location of the mobile receiver unit. However, if the mobile receiving unit has traversed one or more full lanes of either or both families during the period of interruption of operation, the revolution counter or counters **88** and **92** no longer provide accurate lane counts.

In accordance with an important feature of the present invention, however, the ambiguity resolution circuits **69** and **71** may be used to respectively check the lane count of the counters **88** and **92**. Thus, in order to check

the lane counts, the operator makes both a coarse and a medium position check during the respective periods when the signals of the two ambiguity resolution channels are being radiated from the stations **10**, **11** and **12**. The operator is, of course, apprised as to which of the coarse or medium systems is in operation by the illumination of one or the other of the lights **77** and **78**. Assuming first that the medium system is in operation, the slave gate circuit **76** renders the receiver **63** effective to receive the ambiguity resolution signals in the vicinity of 1900 kilocycles so that 95 and 155 cycle beat signals therebetween are produced in the manner described above. The latter signals are passed through the filters **68** and **70** respectively to the circuits **69** and **71** where they are respectively phase compared by the null detectors **93** and **101** with the 95 and 155 cycle reference signals reproduced by the receiver **62** and passed through the filters **72** and **73**. If a direct measurement were made of the phase relationship between the 95 cycle reference signal from the filter **72** and the 95 cycle beat signal from the filter **68**, an indication would be provided to identify the position of the mobile receiving unit relative to a set of hyperbolic isophase lines having foci at the stations **10** and **11**. Similarly, a direct measurement of the phase relationship between the 155 cycle reference signal from the filter **73** and the 155 cycle beat signal from the filter **70** would identify the position of the mobile receiving unit relative to a set of hyperbolic isophase lines having foci at the stations **11** and **12**. The isophase lines of both of the latter sets would be relatively close together since their spacing would be determined by the frequency of the ambiguity resolution channel near 1900 kilocycles. Since such a spacing is not greatly different than that between the isophase lines identified by the meters **80** and **81** the direct measurement of the phases of the two 95 cycle signals and of the two 155 cycle signals would be virtually useless in resolving ambiguity of the fine position indications. However, as was indicated above, in accordance with an important feature of the present invention the phase of one of the 95 cycle signals, for example, that of the reference signal from the filter **72** is shifted by the above-described action of the resolver **84** by an amount equal to the phase displacement between the two 260 cycle signals applied to the terminals **82***a* and **82***b* and, in a similar manner, the phase of one of the 155 cycle signals, for example, the reference signal from the filter **73** is shifted by an amount corresponding to the phase angle between the two 440 signals passed by the filters **66** and **75**.

To understand the effect of this phase shift, consider only the operation of the Green system and assume that the mobile receiving unit starts at a position where the two 260 cycle signals applied to the terminals **82***a* and **82***b* are in phase so that the meter **80** erads zero while, at the same time, the two 95 cycle signals passed by the filters **68** and **72** are also in phase so that the meter **99** is nulled. As the mobile receiving unit **13** is moved in a direction to cut across the hyperbolic lines of the fine Green system the phase difference between signals applied to the terminals **82***a* and **82***b* will change at a faster rate than the phase difference between the signals at the output of the filters **68** and **72**. This is due to the fact that the hyperbolic lines of the fine Green system are spaced as a function of the 2100 kilocycle frequency of the fine system channel and, hence, are somewhat closer together than the isophase lines of the 1900 kilocycle medium channel. More specifically, the lines of the fine system are crossed at a rate of 2100/1900=1.105 times the rate of crossing the lines of the 1900 kilocycle channel. Thus, by the time the mobile receiver has traversed a distance such that the signals at the output of the filters **68** and **72** are again in phase, it has, at the same time, crossed a full lane of the fine Green system plus a fraction of another lane. The amount of the fractional lane crossed is, of course, a function of the frequencies involved but in the example being described it is about 38 degrees. Thus, when the mobile receiver has crossed one lane of the 1900 kilocycle system, the meter **80** will read 38 degrees and a phase shift of 38 degrees will be introduced into the 95 cycle reference signal passed by the filter **72**. Therefore, even though the signals at the output of the filters **68** and **72** are in phase the meter **99** will not indicate a null. Instead, in order to null the two signals applied to the terminals **93***a* and **93***b*, it is necessary to shift the phase of the signal passed by the filter **68** by an amount equal to the phase shift introduced by the resolver **84**. This is accomplished by turning the hand crank **95** by an amount sufficient to turn the rotor of the resolver **94** through an angle of 38 degrees so that the two signals applied to the terminals **93***a* and **93***b* of the null detector are again in phase. When the crank is turned the mechanical connection **96** drives the pointer **97** which cooperates with the scale **98** to indicate that a phase shift of 38 degrees was necessary to restore the balance between the 95 cycle signals.

If the mobile receiving unit **13** is moved from the zero or initial position through two lanes of the 1900 kilocycle system, a null between the 95 cycle signals is otbained by introducing a phase shift of 76 degrees by turning the crank **95** while movement through three such lanes will require a phase shift of **114** degrees and so on. If the 1900.000 kilocycle signals were radiated continuously and if the crank **95** were turned at a rate sufficient to maintain a continuous balance between the 95 cycle signals, the pointer **97** would be continuously driven at a rate corresponding to the rate of crossing hyperbolic isophase lines having foci at the stations **10** and **11** and spaced apart in accordance with a difference frequency of 200 kilocycles which may be termed a phantom frequency equal to the difference between the real frequencies of 2100 and 1900 kilocycles. The scale **98** and the pointer **97** thus provide a position indication identifying the location of the mobile receiving unit with respect to hyperbolic isophase lines having foci at the stations **10** and **11** and spaced apart in accordance with the 200 kilocycle difference frequency. In similar manner, the indicator **104** identifies the location of the mobile unit with respect to isophase lines having foci at the stations **11** and **12** and spaced apart in accordance with the 200 kilocycle difference frequency. These two indications may be referred to as medium or intermediate phase sensitivity indications since the rate at which they change in response to movement of the mobile unit is approximately one-tenth the rate of change of the high phase sensivity indications provided by the meters **80** and **81**. To obtain an actual determination of the position of the mobile unit, the readings on the meters **80** and **81** and those on the meters **98** and **104** may be referred to a chart or nomograph of the area in which the unit **13** is being operated. The latter chart exhibits the isophase lines of both the fine and medium systems.

In operation, the readings on the meters **80** and **81** and the indications on the counters **88** and **92** will be used to establish the position of the mobile craft. The readings on the meters **98** and **104** are then used to determine whether the counters **88** and **92** are accurate. Thus, if the lane count on the counters **88** and **92** is incorrect, the lanes on the chart corresponding to these counts will not be consonant with the medium indications on the meters **98** and **104**. If the lane count on either counter is five counts or less from the correct reading, the operator will be able to use the meter readings **98** and **104** to determine the exact position of the mobile craft whereupon the counters can be reset. However, if the counters are more than five counts off the operator will be unable to determine his position solely by reference to the indicators **98** and **104** because the readings provided by the latter are themselves ambiguous, that is, they repeat every 10.2 lanes of the fine system. In this connection, it should be observed that the null detectors **93** and **101** will provide a false null if the signals applied to their input terminals are more than 180 degrees out of phase. For example, assume that the mobile unit has

moved from the zero position through six lanes of the 1900 kilocycle system to shift the 95 cycle reference signal by 6×38 or 228 degrees in such direction that the reference signal leads the 95 cycle beat signal. The null detector will show that the reference signal lags the beat nal by 360 degrees—228 degrees or 132 degrees thus indicating to the operator that the mobile craft has been moved through about four lanes of the 1900 kilocycle system to shift the reference signal in a negative or lagging direction. Thus, both of the null detectors are incapable of distiguishing phase shifts in excess of 180 degrees and, for this reason, the ambiguity resolution of the medium system is limited to 4.7 lanes of the 1900 kilocycle system or about 5 lanes of the fine system.

To permit the operator to check the counters **88** and **92** for errors in excess of five fine lanes, the coarse system is used. That is, when the transmitting stations **10**, **11** and **12** are radiating ambiguity resolution signals in the vicinity of 2080 kilocycles, these signals are used in the manner described in detail above to produce 95 and 155 cycle reference signals at the outputs of the filters **72** and **73** and to produce 95 and 155 cycle beat signals at the outputs of the filters **68** and **70**. The light **78**, of course, informs the operator that the coarse system is in operation. The two 95 cycle signals are applied to the circuit **69** after phase shifting the reference signal in the manner previously described. The hand crank **95** is then adjusted until the two signals applied to the terminals **93***a* and **93***b* of the null detector are in phase to produce a null on the meter **99**. The meter **98** then provides a coarse or low phase sensitivity position indication representing the location of the mobile craft relative to widely spaced hyperbolic, isophase lines having foci at the transmitting stations **10** and **11** and spaced apart in accordance with the 20 kilocycle difference between the 2100 kilocycle fine position indicating signals and 2080 kilocycle coarse ambiguity resolution signals. In similar manner, the two 155 cycle signals are passed to the circcircuit **71** after phase shifting the reference signal and the hand crank **102** is adjusted to bring the two input signals to the null detector **101** into phase and, hence, to produce a null on the meter **106**. The meter **104** then provides a coarse or low phase sensitivity indication representing the location of the mobile craft relative to widely spaced hyperbolic, isophase lines having foci at the stations **11** and **12**, the spacing again being a function of the 20 kilocycle difference between the 2100 kilocycle position indicating signals and the 2080 kilocycle coarse ambiguity resolution signals.

As will be apparent from the foregoing description, the coarse indications provided by the meters **98** and **104** have a phase sensitivity which is only about one-tenth that of the medium indications and is about one-hundredth that of the fine position indications on the meters **80** and **81**. The coarse indications, for reasons which will be obvious in view of the above description, will resolve ambiguities in the fine position indications within about 50 fine lanes and, as a result, if the operator at the mobile craft is able to determine his position within 50 lanes he can set the counters **88** and **92** to the proper lane count by using the coarse and medium indications in the manner described above. The approximation of the mobile craft position can be made in any manner well known in the art as, for example, by use of a rotatable directional antenna to provide nulls or peaks on signals from the stations **10**, **11** and **12**. Of course, the approximation could also be made by reference to a known geographic location such as a fixed buoy or in any other well known manner. The coarse and fine position indications by themselves may not be sufficient to provide an unambiguous position indication since the error in the coarse indications may be greater than one lane of the fine system. However, the medium position indications take care of this possibility by providing lane identification for the fine system while the coarse indications accurately identify the lane of the medium system and, as a consequence, accurate and unambiguous position indications may be provided within 50 lanes of the fine system.

FIG. 4 shows another mobile receiving unit **113** capable of use in the transmitting system shown in FIG. 2. The primary difference between the units shown in FIGS. 3 and 4 is the use in the latter of a single normally operated crank **195** for both the Green and Red lane identification circuits as compared with the use of separate mechanisms in the receiving unit **13** described above. Since many of the components of the mobile receiving unit **113** are identical to those used in the unit **13** these identical components have been assigned the same reference numerals and will not be described in detail. The existing mobile receiving equipment for providing the fine position indications has been enclosed within broken lines **113***a* and this equipment is essentially the same as that enclosed within the lines **13***a* in FIG. 3, the only difference being the connections of the output members or synchros. Thus, the output resolvers or synchro transmitters bear the numerals **184** and **191** and have their rotors driven from the servo-rotors of the circuits **82** and **90**, respectively, in exactly the same manner as described above. The meters **80** and **81**, therefore, function as previously described to provide fine or high phase sensitivity position indications. The stator windings of the synchro transmitters **184** and **191** are not excited by the reference signals from the filters **72** and **73** and in this respect they differ from the resolvers **84** and **91** described above. Instead, the rotor windings of the transmitters **184** and **191** are excited by a suitable A.C. signal such as a 60 cycle signal derived from the power supply. This A.C. signal induces in the stator windings an output signal of identical frequency but having a phase which is a function of the angular position occupied by the rotor of the synchro transmitter. The signals induced in the stators of the synchro transmitters **184** and **191** are respectively supplied to the lane identification circuit **169** via conductors **187** and **205**.

The lane identification circuit **169** includes, in addition to the single crank **195** referred to above, a four section, two position, manually operated base line switch **120**, a null detector **193** like the detector **93** described above, a meter **199**, a synchro receiver **130**, a resolver **194**, an indicator **198**, and a pair of phase networks **140** and **141** for the audio signals of 95 and 155 cycles, respectively. The switch **120** comprises four sections **121**, **122**, **123** and **124** having movable poles ganged together for operation in unison and movable to two different positions one of which may be referred to as the Green position and the other of which may be referred to as the Red position. The switch **120** is shown in FIG. 4 in the Red position wherein the section **121** is effective to supply A.C. signals from the conductor **205** to the stator windings of the synchro receiver **130**. The synchro receiver cooperates with the resolver **194** to introduce into one of the beat signals a phase shift equal to the phase angle between the audio signals of the fine system. The phase shift introduced serves the same purpose as that provided by the resolvers **84** and **91** of the mobile receiving unit **13** previously described. More specifically, with the switch **120** in the Red position as shown in FIG. 4, the 155 cycle beat signal passed by the filter **70** is applied through the switch section **123** to the stator windings of the resolver **194**. The rotor of this resolver is mechanically connected to the rotor of the synchro receiver **130**. As will be understood by those familiar with the operation of servos or synchros the rotor of the synchro receiver **130** is driven by the A.C. signal applied to its stator windings until the rotor occupies an angular position identical to that of the rotor of the synchro transmitter **191**. The rotor of the resolver **194**, of course, occupies the same angular position as the rotor of the synchro receiver **130**. The 155 cycle signal induced in the rotor winding of the resolver **194** is applied to the phase networks **140** and **141** but this signal is

shifted in phase through an angle equal to that measured by the meter **81** which is, of course, a measure of the phase relationship between the 440 cycle signals passed by the filters **66** and **75** to the phase comparison circuit **67**. Each network includes an adjustable phase shifting circuit for introducing a small phase shift to compensate for undesired phase shifts which occur as the audio signals pass through the components of the mobile receiving unit. Since the amount of these undesired phase shifts may differ for the 95 cycle and 155 cycle signals separate networks are necessary. In any event, with the switch **120** in the Red position, the 155 cycle signal from the resolver **194** passes through the network **141** and through the switch section **124** to the input terminals **193***b* of the null detector **193**. The other set of input terminals **193***a* of the null detector is excited by the 155 cycle reference signal from the filter **73**, this reference signal being supplied through the switch section **122**. As was described in detail above in connection with the description of the detector **93** and its associated meter **99**, a null or zero indication is provided on the meter **199** when the input signals to the terminals **193***a* and **193***b* are in phase but, when these signals are out of phase, the null detector produces a D.C. signal to deflect the meter position by an amount proportional to the magnitude of the phase deviation and in a direction indicative of the direction of the phase deviation. If the meter **199** indicates that the signals applied to the terminals **193***a* and **193***b* are not in phase, the operator at the mobile unit turns the crank **195** in a proper direction to shift the phase of the beat signal until the in-phase relationship is achieved. To this end, the crank is mechanically connected to the case of the resolver **194** as indicated by the broken line **203**. Thus, when the crank is turned the resolver case carrying the stator windings is also turned to shift the phase of the 155 cycle beat signal supplied to the networks **140** and **141**. The crank and its associated mechanical connection **203** also drive the pointer **197** of the indicator **198** so that the latter indicates the angular position of the crank.

In view of the foregoing description, it will be recognized that with the switch **120** in the Red position and with the transmitting stations radiating signals in the ambiguity resolution channel near 1900 kilocycles the crank **195** may be turned by the operator until a null is obtained on the meter **199** whereupon the indicator **198** provides a medium or intermediate phase sensitivity indication representing the location of the mobile craft relative to hyperbolic isophase lines having foci at the stations **11** and **12** and spaced apart in accordance with the 200 kilocycle phantom frequency difference between the 1900 kilocycle poistion indicating signals. Similarly, when the transmitting stations **10, 11** and **12** are radiating their coarse ambiguity resolution signals in the vicinity of 2080 kilocycles, the crank **195** may be turned to obtain a null on the meter **199** whereupon the indicator **198** provides a coarse or low phase sensitivity indication representing the location of the mobile craft relative to widely spaced hyperbolic isophase lines having foci at the stations **11** and **12** and spaced apart in accordance with the 20 kilocycle phantom frequency difference between the 2100 kilocycle fine position indicating signals and the 2080 kilocycle coarse ambiguity resolution signals. As is apparent from the above description, the medium and coarse position indications just described will provide a check on the accuracy of the counter **92** for the Red system indicator as long as the operator can determine his position within about 50 lanes of the fine Red system.

To check the accuracy of the counter **88** for the Green system, the operator throws the switch **120** to the Green position whereupon the switch section **121** supplies A.C. signals from the conductor **187** to the stator windings of the synchro receiver **130**. The rotor of the synchro receiver is thus driven to an angular position identical with that of the rotor of the synchro transmitter **184**. The switch section **122** supplies 95 cycle reference signals from the filter **72** to the terminal **193***a* of the null detector **193** and the switch section **123** supplies 95 cycle beat signals from the filter **68** to the stator windings of the resolver **194**. The 95 cycle signals induced in the rotor winding of the latter resolver are passed through the network **140** and through the switch section **124** to the terminals **193***b* of the null detector. The latter 95 cycle signals are, of course, phase shifted in the resolver **194** by an amount equal to the angular position of the pointer **86** of the Green system indicator **80**.

To obtain a medium Green position indication with the stations **10, 11** and **12** radiating ambiguity resolution signals in the vicinity of 1900 kilocycles, the operator tuurns the crank **195** until the meter **199** indicates a null whereupon the indicator **198** provides a medium phase sensitivity position indication representing the location of the mobile craft relative to hyperbolic isophase lines having foci at the stations **10** and **11** and spaced apart in accordance with the 200 kilocycle phantom frequency difference between the 2100 kilocycle position indicating signals and the 1900 kilocycle medium ambiguity resolution signals. A coarse position indication for the Green system is obtained in an obvious manner when the transmitting stations **10, 11** and **12** are effective to radiate their coarse ambiguity resolution signals in the vicinity of 2080 kilocycles. The medium and coarse indications for the Green system are referred to a computer, chart or nomograph to check the lane count on the counters **88**. If the operator can determine fine position within 50 lanes of the fine Green system the medium and coarse position indications will enable an accurate determination of the correctness of the Green system counter.

FIG. 5 illustrates still another form of mobile receiving unit **213** which may be used with the transmitting system of FIG. 2. The receiving unit **213** differs from the unit **113** principally in the provision of means in the lane identification facilities **213***b* for automatically shifting the phases of the lane identification beat signals without resort to a manually operated crank or the like. Essentially, this is acomplished by replacing the null detector **193**, the associated meter **199** and the hand crank **195** with a servo-mechanism including a phase discriminator and servo-amplifier circuit **240** and a servo-motor **241** for driving the mechanical connection **203** to the case of the resolver **194**. Since most of the components of the mobile receiving unit **213** are identical to those of the unit **113** described above, identical reference numerals have again been used to avoid the necessity for detailed description of these components.

To accomplish the aforementioned automatic phase shifting of the 95 and 155 cycle beat signals from the filters **68** and **70**, one set of input terminals **240***a* of the servo-amplifier circuit **240** is excited by reference signals supplied via a conductor **242** from section **122** of the base line selector switch **120** while the other set of input terminals **240***b* is supplied with beat signals from the switch section **124**. Signals of identical frequency are, of course, supplied to the circuit **240** since the switch **120** will select either 95 cycle or 155 cycle signals depending upon whether the Green system or Red system counters are to be checked. The circuit **240** is similar to the circuit **82** described above and functions to provide a D.C. output signal to the servo-motor **241** whenever the two input signals are out of phase. The amplitude of the D.C. signal supplied to the motor **241** is a function of the magnitude of the phase difference between the input signals while the polarity of the signal is a function of the direction of the phase deviation. The motor **241** acts through the drive correction **203** to turn the case of the resolver **194** and its stator windings, thus shifting the phase of the beat signal otuput from the resolver in a direction to bring it into phase with the reference signal applied to the input terminals **240***a*. The servo system is, thus, in the form of a conventional balanced loop.

and when the two input signals to the circuit **240** are in phase no drive signal is supplied to the motor **241**.

To check the accuracy of the counter **92** for the Red system the operator places the switch **120** in the Red position shown in FIG. 5 whereupon A.C. signals from the synchro transmitter **191** are applied to the synchro receiver **130** to drive both the rotor of the receiver and that of the resolver **194** to a position corresponding to that of the pointer **86** of the Red system meter **81**. The stator windings of the resolver **194** receive 155 cycle beat signals from the filter **70** through the switch section **123** and these signals, after undergoing a phase shift equal to the angle of the pointer **86**, are applied through the network **141** and through the switch section **124** to the terminals **240***b* of phase discriminator and servo-amplifier circuit **240**. The input terminals **240***a* of the latter circuit receive 155 cycle reference signals from the filter **73** through the switch section **122**. If the two 155 cycle input signals to the circuit **240** are not in phase the servo-motor **241** is immediately driven in a direction to turn the case of the resolver **194** until the in-phase condition is reached. The pointer **197** is driven to indicate the position of the output shaft of the servo-motor. In view of the foregoing description, it will be obvious that a medium position indication for the Red system is provided by the meter **198** when the transmitting stations **10**, **11** and **12** are effective to radiate the medium ambiguity resolution signals in the vicinity of 1900 kilocycles while a coarse indication is provided when the coarse ambiguity resolution signals near 2080 kilocycles are being radiated. As was indicated above, the Red system counter can be accurately checked by resort to the medium and coarse position indications as long as the position of the craft can be determined within 50 lanes.

To check the accuracy of the counter **88** for the Green system, the switch **120** is thrown to the Green position whereupon coarse and medium position indications for the Green system will be automatically obtained in a manner which is obvious from the above description. Both the Red and Green medium and coarse position indications are produced with a minimum time and effort on the part of the operator since the operator is required only to manipulate the switch **120** and to transfer the readings on the indicator **198** to the chart or nomograph.

In view of the foregoing description, it will be recognized that the systems described are effective to perform the enumerated objects of the invention. The transmitting facilities may be utilized with any number of mobile receiving units and, in the event that some of these units are of the type presently in use and not equipped with an ambiguity resolution system like that described, the latter units will, nevertheless, be effective to provide the fine position indications although obviously no means will be provided for checking the lane counts appearing on their integrating counters.

While particular embodiments of the invention have been illustrated and described, it will be recognized that many modifications will readily occur to those skilled in this art and it is therefore contemplated by the appended claims to cover any such modifications as fall within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In a transmitting system for use in a three foci hyperbolic, continuous wave, position finding system, first, second and third fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for alternately radiating first and second ambiguity resolution signals, the first ambiguity resolution signals radiated from the three fixed stations differing in frequency from each other but lying within a second frequency channel which is distinguishable from the first frequency channel, the second ambiguity resolution signals radiated from the three fixed stations also differing from each other but lying within a third frequency channel which is distinguishable from the first and second channels, the frequency difference between the first ambiguity resolution signals radiated from the first and second stations being equal to the frequency difference between the second ambiguity resolution signals radiated from the first and second stations and the frequency difference between the first ambiguity resolution signals radiated from the second and third stations being equal to the frequency difference between the second ambiguity resolution signals radiated from the second and third stations, a reference transmitting station radiating a carrier wave having a frequency distinguishable from said first, second and third frequency channels, means for coding the carrier wave radiated from said reference station, means at each of said fixed transmitting stations for receiving the coded carrier wave and for developing therefrom a control signal, means at each of said fixed transmitting stations responsive to the control signal for rendering each of the latter stations alternately effective to radiate its two ambiguity resolution signals, with said three fixed stations being rendered effective to radiate simultaneously the ambiguity resolution signals of the second channel during a first interval and to radiate simultaneously the ambiguity resolution signals of the third channel during a second interval, first receiving means at the reference station for receiving the position indicating signals radiated from all three fixed stations, second receiving means at the reference station for receiving the ambiguity resolution signals in said second and third frequency channels, means for rendering said second receiving means effective to receive the ambiguity resolution signals of the second channel during the first of said intervals and for rendering the second receiving means effective to receive the signals of the third channel during the second interval, said second receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in pairs during the first interval in order to develop a first difference signal from the first ambiguity resolution signals radiated from the first and second stations and to develop a second difference signal from the first ambiguity resolution signals radiated from the second and third stations, said second receiving means also being effective to heterodyne the ambiguity resolution signals of the third channel in pairs during the second interval in order to develop a third difference signal from the second ambiguity resolution signals radiated from the first and second stations and to develop a fourth difference signal from the second ambiguity resolution signals radiated from the second and third stations, said first receiving means being effective to heterodyne the position indicating signals in pairs in order to develop a fifth difference signal from the position indicating signals radiated from the first and second stations and to develop a sixth difference signal from the position indicating signals radiated from the second and third stations, and means for modulating said carrier wave with reference signals respectively derived from said first, second, third, fourth, fifth and sixth difference signals.

2. In a transmitting system for use in a three foci hyperbolic, continuous wave, position finding system, first, second and third fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for alternately radiating first and second ambiguity resolution signals, the first ambiguity resolution signals radiated from the three fixed stations differing in frequency from each other but lying within a second frequency channel which is distinguishable from the first frequency channel, the second ambiguity resolution signals radiated from the three fixed stations also differing from each other but lying within a

third frequency channel which is distinguishable from the first and second channels, the frequency difference between the first ambiguity resolution signals radiated from the first and second stations being equal to the frequency difference between the second ambiguity resolution signals radiated from the first and second stations and the frequency difference between the first ambiguity resolution signals radiated from the second and third stations being equal to the frequency difference between the second ambiguity resolution signals radiated from the second and third stations, a reference transmitting station radiating a carrier wave having a frequency distinguishable from said first, second and third frequency channels, means for coding the carrier wave radiated from said reference station, means at each of said fixed transmitting stations for receiving the coded carrier wave and for developing therefrom a control signal, means at each of said fixed transmitting stations responsive to the control signal for rendering each of the latter stations alternately effective to radiate its two ambiguity resolution signals, with said three fixed stations being rendered effective to radiate simultaneously the ambiguity resolution signals of the second channel during a first interval and to radiate simultaneously the ambiguity resolution signals of the third channel during a second interval, receiving means at the reference station for receiving the position indicating signals radiated from all three fixed stations and for receiving the ambiguity resolution signals in said second and third frequency channels, said receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in pairs during the first interval in order to develop a first difference signal from the first ambiguity resolution signals radiated from the first and second stations and to develop a second difference signal from the first ambiguity resolution signals radiated from the second and third stations, said receiving means also being effective to heterodyne the ambiguity resolution signals of the third channel in pairs during the second interval in order to develop a third difference signal from the second ambiguity resolution signals radiated from the first and second stations and to develop a fourth difference signal from the second ambiguity resolution signals radiated from the second and third stations, said receiving means being effective to heterodyne the position indicating signals in pairs in order to develop a fifth difference signal from the position indicating signals radiated from the first and second stations and to develop a sixth difference signal from the position indicating signals radiated from the second and third stations, and means for modulating said carrier wave with reference signals respectively derived from said first, second, third, fourth, fifth and sixth difference signals.

3. In a transmitting system for use in a three foci hyperbolic, continuous wave, position finding system, first, second and third fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for alternately radiating first and second ambiguity resolution signals, the first ambiguity resolution signals radiated from the three fixed stations differing in frequency from each other but lying within a second frequency channel which is distinguishable from the first frequency channel, the second ambiguity resolution signals radiated from the three fixed stations also differing from each other but lying within a third frequency channel which is distinguishable from the first and second channels, said three fixed stations being rendered effective to radiate simultaneously the ambiguity resolution signals of the second channel during a first interval and to radiate simultaneously the ambiguity resolution signals of the third channel during a second interval, the frequency difference between the first ambiguity resolution signals radiated from the first and second stations being equal to the frequency difference between the second ambiguity resolution signals radiated from the first and second stations and the frequency difference between the first ambiguity resolution signals radiated from the second and third stations being equal to the frequency difference between the second ambiguity resolution signals radiated from the second and third stations, a reference transmitting station radiating a carrier wave having a frequency distinguishable from said first, second and third frequency channels, first receiving means at the reference station for receiving the position indicating signals radiated from all three fixed stations, second receiving means at the reference station for receiving the ambiguity resolution signals in said second and third frequency channels, means for rendering said second receiving means effective to receive the ambiguity resolution signals of the second channel during the first of said intervals and for rendering the second receiving means effective to receive the signals of the third channel during the second interval, said second receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in pairs during the first interval in order to develop a first difference signal from the first ambiguity resolution signals radiated from the first and second stations and to develop a second difference signal from the first ambiguity resolution signals radiated from the second and third stations, said second receiving means also being effective to heterodyne the ambiguity resolution signals of the third channel in pairs during the second interval in order to develop a third difference signal from the second ambiguity resolution signals radiated from the first and second stations and to develop a fourth difference signal from the second ambiguity resolution signals radiated from the second and third stations, said first receiving means being effective to heterodyne the position indicating signals in pairs in order to develop a fifth difference signal from the position indicating signals radiated from the first and second stations and to develop a sixth difference signal from the position indicating signals radiated from the second and third stations, and means for modulating said carrier wave with reference signals respectively derived from said first, second, third, fourth, fifth and sixth difference signals.

4. In a transmitting system for use in a three foci hyperbolic, continuous wave, position finding system, first, second and third fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for alternately radiating first and second ambiguity resolution signals, the first ambiguity resolution signals radiated from the three fixed stations differing in freqeuncy from each other but lying within a second frequency channel which is distinguishable from the first frequency channel, the second ambiguity resolution signals radiated from the three fixed stations differing in frequency from each other but lying a third frequency channel which is distinguishable from the first and second channels, said three fixed stations being rendered effective to radiate simultaneously the ambiguity resolution signals of the second channel during a first interval and to radiate simultaneously the ambiguity resolution signals of the third channel during a second interval, the frequency difference between the first ambiguity resolution signals radiated from the first and second stations being equal to the frequency difference between the second ambiguity resolution signals radiated from the first and second sections and the frequency difference between the first ambiguity resolution signals radiated from the second and third stations being equal to the frequency difference between the second ambiguity resolution signals radiated from the second and third stations, a reference transmitting station radiating a carrier wave having a frequency distinguishable from said first, second and third frequency channels, receiving means at the reference station for receiving the position

indicating signals radiated from all three fixed stations and for receiving the ambiguity resolution signals in said second and third frequency channels, said receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in pairs during the first interval in order to develop a first difference signal from the first ambiguity resolution signals radiated from the first and second stations and to develop a second difference signal from the first ambiguity resolution signals radiated from the second and third stations, said receiving means also being effective to heterodyne the ambiguity resolution signals of the third channel in pairs during the second interval in order to develop a third difference signal from the second ambiguity resolution signals radiated from the first and second stations and to develop a fourth difference signal from the second ambiguity resolution signals radiated from the second and third stations, said receiving means also being effective to heterodyne the position indicating signals in pairs in order to develop a fifth difference signal from the position indicating signals radiated from the first and second stations and to develop a sixth difference signal from the position indicating signals radiated from the second and third stations, and means for modulating said carrier wave with reference signals respectively derived from said first, second, third, fourth, fifth and sixth difference signals.

5. In a transmitting system for use in a three foci hyperbolic, continuous wave, position finding system, first, second and third fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differeing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for alternately radiating first and second ambiguity resolution signals, the first ambiguity resolution signals radiated from the three fixed stations differing in frequency from each other but lying within a second frequency channel which is distinguishable from the first frequency channel, the second ambiguity resolutions signals radiated from the three fixed stations also differing from each other but lying within a third frequency channel which is distinguishable from the first and second channels, a reference transmitting station radiating a carrier wave having a frequency distinguishable from said first, second and third frequency channels, means for coding the carrier wave radiated from said reference station, means at each of said fixed transmitting stations for receiving the coded carrier wave and for developing therefrom a control signal, means at each of said fixed transmitting stations responsive to the control signal for rendering each of the latter stations alternately effective to radiate its two ambiguity resolution signals, with said three fixed stations being rendered effective to radiate simultaneously the ambiguity resolution signals of the second channel during a first interval and to radiate simultaneously the ambiguity resolution signals of the third channel during a second interval, first receiving means at the reference station for receiving the position indicating signals radiated from all three fixed stations, second receiving means at the reference station for receiving the ambiguity resolution signals in said second and third frequency channels, means for rendering said second receiving means effective to receive the ambiguity resolution signals of the second channel during the first of said intervals and for rendering the second receiving means effective to receive the signals of the third channel during the second interval, said second receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in pairs during the first interval in order to develop a first difference signal from the first ambiguity resolution signals radiated from the first and second stations and to develop a second difference signal from the first ambiguity resolution signals radiated from the second and third stations, said second receiving means also being effective to heterodyne the ambiguity resolution signals of the third channel in pairs during the second interval in order to develop a third difference signal from the second ambiguity resolution signals radiated from the first and second stations and to develop a fourth difference signal from the second ambiguity resolution signals radiated from the second and third stations, said first receiving means being effective to heterodyne the position indicating signals in pairs in order to develop a fifth difference signal from the position indicating signals radiated from the first and second stations and to develop a sixth difference signal from the position indicating signals radiated from the second and third stations, and means for modulating said additional signals with reference signals respectively derived from said first, second, third, fourth, fifth and sixth difference signals.

6. In a transmitting system for use in a three foci hyperbolic, continuous wave, position finding system, first, second and third fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for alternately radiating first and second ambiguity resolution signals, the first ambiguity resolution signals radiated from the three fixed stations differing in frequency from each other but lying within a second frequency channel which is distinguishable from the first frequency channel, the second ambiguity resolution signals radiated from the three fixed stations also differing from each other but lying within a third frequency channel which is distinguishable from the first and second channels, said three fixed stations being rendered effective to radiate simultaneously the ambiguity resolution signals of the second channel during a first interval and to radiate simultaneously the ambiguity resolution signals of the third channel during a second interval, a reference transmitting station radiating additional signals, first receiving means at the reference station for receiving the position indicating signals radiated from all three fixed stations, second receiving means at the reference station for receiving the ambiguity resolution signals in said second and third frequency channels, means for rendering said second receiving means effective to receive the ambiguity resolution signals of the second channel during the first of said intervals and for rendering the second receiving means effective to receive the signals of the third channel during the second interval, said second receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in pairs during the first interval in order to develop a first difference signal from the first ambiguity resolution signals radiated from the first and second stations and to develop a second difference signal from the first ambiguity resolution signals radiated from the second and third stations, said second receiving means also being effective to heterodyne the ambiguity resolution signals of the third channel in pairs during the second interval in order to develop a third difference signal from the second ambiguity resolution signals radiated from the first and second stations and to develop a fourth difference signal from the second ambiguity resolution signals radiated from the second and third stations, said first receiving means being effective to heterodyne the position indicating signals in pairs in order to develop a fifth difference signal from the position indicating signals radiated from the first and second stations and to develop a sixth difference signal from the position indicating signals radiated from the second and third stations, and means for modulating said additional signals with reference signals respectively derived from said first, second, third, fourth, fifth and sixth difference signals.

7. In a transmitting system for use in a two foci hyperbolic, continuous wave, location system, first and second fixed transmitting stations each continuously radiating a position indicating signal with said position indicating

signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for radiating first and second ambiguity resolution signals alternately with each other, the first ambiguity resolution signals radiated from the two fixed stations differing from each other in frequency but falling within a second frequency channel, the second ambiguity resolution signals radiated from the two fixed stations also differing from each other in frequency but falling within a third frequency channel, the frequency difference between the two ambiguity resolution signals of the second channel being equal to that between the two ambiguity resolution signals of the third channel, a reference transmitting station spaced from said first and second stations for radiating a carrier wave having a frequency distinguishable from all of said first, second and third frequency channels, means for coding the carrier wave radiated from said reference station, means at each of said fixed transmitting stations for receiving the coded carrier wave and producing therefrom a control signal, means at each of said fixed transmitting stations responsive to the control signal for rendering each of the latter stations alternately effective to radiate the two ambiguity resolution signals with the ambiguity resolution signals of the second channel being radiated simultaneously from said first and second stations during a first interval and with the ambiguity resolution signals of the third channel also being radiated simultaneously from the first and second stations during a second interval, first receiving means at the reference station for receiving the position indicating signals radiated from both of the fixed stations, second receiving means at the reference station for receiving the signals of both of said second and third channels, means for rendering said second receiving means effective to receive the signals of the second channel during the first interval and for rendering the second receiving means effective to receive the signals of the third channel during the second interval, said second receiving means being effective during the first interval to heterodyne the ambiguity resolution signals of the second channel in order to develop a first difference signal and also effective during the second interval to heterodyne the ambiguity resolution signals of the third channel to develop a second difference signal, said first receiving means being effective to heterodyne the position indicating signals to develop a third difference signal, and means for modulating said carrier wave with reference signals respectively derived from said first, second and third difference signals.

8. In a transmitting system for use in a two foci hyperbolic, continuous wave, location system, first and second fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for radiating first and second ambiguity resolution signals alternately with each other, the first ambiguity resolution signals radiated from the two fixed stations differing from each other in frequency but falling within a second frequency channel, the second ambiguity resolution signals radiated from the two fixed stations also differing from each other in frequency but falling within a third frequency channel, the frequency difference between the two ambiguity resolution signals of the second channel being equal to that between the two ambiguity resolution signals of the third channel, a reference transmitting station spaced from said first and second stations for radiating a carrier wave having a frequency distinguishable from all of said first, second and third frequency channels, means for coding the carrier wave radiated from said reference station, means at each of said fixed transmitting stations for receiving the coded carrier wave and producing therefrom a control signal, means at each of said fixed transmitting stations responsive to the control signal for rendering each of the latter stations alternately effective to radiate the two ambiguity resolution signals with the ambiguity resolution signals of the second channel being radiated simultaneously from said first and second stations during a first interval and with the ambiguity resolution signals of the third channel also being radiated simultaneously from the first and second stations during a second interval, receiving means at the reference station for receiving the position indicating signals radiated from both of the fixed stations and for receiving the signals for both of said second and third channels, said receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in order to develop a first difference signal to heterodyne the ambiguity resolution signals of the third channel to develop a second difference signal and to heterodyne the position indicating signals to develop a third difference signal, and means for modulating said carrier wave with reference signals respectively derived from said first, second and third difference signals.

9. In a transmitting system for use in a two foci hyperbolic, continuous wave, location system, first and second fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for radiating first and second ambiguity resolution signals altrenately with each other, the first ambiguity resolution signals radiated from the two fixed stations differing from each other in frequency but falling within a second frequency channel, the second ambiguity resolution signals radiated from the two fixed stations also differing from each other in frequency but falling within a third frequency channel, a reference transmitting station spaced from said first and second stations for radiating additional signals, means for coding the additional signals radiated from said reference station, means at each of said fixed transmitting stations for receiving the coded additional signals and producing therefrom a control signal, means at each of said fixed transmitting stations responsive to the control signal for rendering each of the latter stations alternately effective to radiate the two ambiguity resolution signals with the ambiguity resolution signals of the second channel being radiated simultaneously from said first and second stations during a first interval and with the ambiguity resolution signals of the third channel also being radiated simultaneously from the first and second stations during a second interval, receiving means at the reference station for receiving the position indicating signals radiated from both of the fixed stations and for receiving the signals of both of said second and third channels, said receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in order to develop a first difference signal, to heterodyne the ambiguity resolution signals of the third channel to develop a second difference signal to heterodyne the position indicating signals to develop a third difference signal, and means for modulating said additional signals with reference signals respectively derived from said first, second and third difference signals.

10. In a transmitting system for use in a two foci hyperbolic, continuous wave, location system, first and second fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for radiating first and second ambiguity resolution signals alternately with each other, the first ambiguity resolution signals radiated from the two fixed stations differing from each other in frequency but falling within a second frequency channel, the second ambiguity resolution signals radiated from the two fixed stations also differing from each other in frequency but falling within a third frequency channel, the ambiguity resolution signals of the second channel being radiated simul-

taneously from said first and second stations during a first interval and the ambiguity resolution signals of the third channel also being radiated simultaneously from the first and second stations during a second interval, the frequency difference between the two ambiguity resolution signals of the second channel being equal to that between the two ambiguity resolution signals of the third channel, a reference transmitting station radiating a carrier wave having a frequency distinguishable from all of said first, second and third frequency channels, first receiving means at the reference station for receiving the position indicating signals radiated from both of the fixed stations, second receiving means at the reference station for receiving the signals of both of said second and third channels, means for rendering said second receiving means effective to receive the signals of the second channel during the first interval and for rendering the second receiving means effective to receive the signals of the third channel during the second interval, said second receiving means being effective during the first interval to heterodyne the ambiguity resolution signals of the second channel in order to develop a first difference signal and also effective during the second interval to heterodyne the ambiguity resolution signals of the third channel to develop a second difference signal, said first receiving means being effective to heterodyne the position indicating signals to develop a third difference signal, and means for modulating said carrier wave with reference signals respectively derived from said first, second and third difference signals.

11. In a transmitting system for use in a two foci hyperbolic, continuous wave, location system, first and second fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for radiating first and second ambiguity resolution signals alternately with each other, the first ambiguity resolution signals radiated from the two fixed stations differing from each other in frequency but falling within a second frequency channel, the second ambiguity resolution signals radiated from the two fixed stations also differing from each other in frequency but falling within a third frequency channel, the ambiguity resolution signals of the second channel being radiated simultaneously from said first and second stations during a first interval and the ambiguity resolution signals of the third channel also being radiated simultaneously from the first and second stations during a second interval, a reference transmitting station radiating additional signals, first receiving means at the reference station for receiving the position indicating signals radiated from both of the fixed stations, second receiving means at the reference station for receiving the signals of both of said second and third channels, means for rendering said second receiving means effective to receive the signals of the second channel during the first interval and for rendering the second receiving means effective to receive the signals of the third channel during the second interval, said second receiving means being effective during the first interval to heterodyne the ambiguity resolution signals of the second channel in order to develop a first difference signal and also effective during the second interval to heterodyne the ambiguity resolution signals of the third channel to develop a second difference signal, said first receiving means being effective to heterodyne the position indicating signals to develop a third difference signal, and means for modulating said additional signals radiated from the reference station with reference signals respectively derived from said first, second and third difference signals.

12. In a transmitting system for use in a two foci hyperbolic, continuous wave, location system, first and second fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for radiating first and second ambiguity resolution signals alternately with each other, the first ambiguity resolution signals radiated from the two fixed stations differing from each other in frequency but falling within a second frequency channel, the second ambiguity resolution signals radiated from the two fixed stations also differing from each other in frequency but falling within a third frequency channel, the ambiguity resolution signals of the second channel being radiated simultaneously from said first and second stations during a first interval and the ambiguity resolution signals of the third channel also being radiated simultaneously from the first and second stations during a second interval, the frequency difference between the two ambiguity resolution signals of the second channel being equal to that between the two ambiguity resolution signals of the third channel, a reference transmitting station radiating a carrier wave having a frequency distinguishable from all of said first, second and third frequency channels, receiving means at the reference station for receiving the position indicating signals radiated from both of the fixed stations and for receiving the signals of both of said second and third channels, said receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in order to develop a first difference signal, to heterodyne the ambiguity resolution signals of the third channel to develop a second difference signal, and to heterodyne the position indicating signals to develop a third difference signal, and means for modulating said carrier wave with reference signals respectively derived from said first, second and third difference signals.

13. In a transmitting system for use in a two foci hyperbolic, continuous wave, location system, first and second fixed transmitting stations each continuously radiating a position indicating signal with said position indicating signals differing from each other in frequency but falling within a first frequency channel, means at each of said fixed stations for radiating first and second ambiguity resolution signals alternately with each other, the first ambiguity resolution signals radiated from the two fixed stations differing from each other in frequency but falling within a second frequency channel, the second ambiguity resolution signals radiated from the two fixed stations also differing from each other in frequency but falling within a third frequency channel, the ambiguity resolution signals of the second channel being radiated simultaneously from said first and second stations during a first interval and the ambiguity resolution signals of the third channel also being radiated simultaneously from the first and second stations during a second interval, the frequency difference between the two ambiguity resolution signals of the second channel being equal to that between the two ambiguity resolution signals of the third channel, a reference transmitting station for radiating additional signals, first receiving means at the reference station for receiving the position indicating signals radiated from both of the fixed stations and for receiving the signals of both of said second and third channels, said receiving means being effective to heterodyne the ambiguity resolution signals of the second channel in order to develop a first difference signal, to heterodyne the ambiguity resolution signals of the third channel to develop a second difference signal, and the position indicating signals to develop a third difference signal, and means for modulating the additional signals radiated from the reference station with reference signals respectively derived from said first, second and third difference signals.

14. Mobile receiving equipment for use in radio location systems of the hyperbolic, continuous wave type radiating from spaced points at least two position indicating signals and at least two ambiguity resolution signals, said position indicating signals differing from each other in frequency but falling within a first channel, said ambiguity resolution signals also differing from each other

but falling within a second channel distinguishable from the first channel, said system being of the type wherein the position indicating signals are heterodyned at a fixed point in the system to develop a first difference frequency while the ambiguity resolution signals are similarly heterodyned to develop a second difference frequency and wherein said first and second difference frequencies are respectively used to produce first and second reference signals modulated upon at least one carrier wave, said mobile receiving equipment comprising means for receiving all of said signals to detect the first and second reference signals, to heterodyne the position indicating signals to develop a first beat frequency and to heterodyne the ambiguity resolution signals to develop a second beat frequency, means for comparing the phase of the first beat frequency with that of the first reference signal to develop a first position indication accurately representing the location of the mobile receiving equipment relative to a first set of hyperbolic isophase lines having foci at said spaced points, a lane identification circuit jointly responsive to said second beat frequency and to said second reference signal, phase shifting means operated by said comparing means for phase shifting one of the two last mentioned signals by an amount which is a function of the position of the mobile receiving equipment relative to said first set of hyperbolic isophase lines, said lane identification circuit including comparison means responsive to the phase relationship between the output of the phase shifting means and the other of said two last mentioned signals, means for introducing another phase shift into one of said two last mentioned signals, said another phase shift being sufficient to establish a predetermined phase relationship between the two signals to which the comparison means responds, and means for measuring the amount of said another phase shift to provide a second position indication relative to a second set of hyperbolic lines having foci at said spaced points but spaced farther apart than the first set so that said second position indication is less accurate than said first position indication but is useful in resolving ambiguities of the first indication, the spacing of the second set of hyperbolic lines being a function of the frequency difference between the first and second channels.

15. The apparatus defined by claim **14** wherein the means for introducing said another phase shift comprises a servo mechanism operated automatically by said two last mentioned signals.

16. Mobile receiving equipment for use in radio location systems of the hyperbolic, continuous wave type radiating from spaced points at least two position indicating signals and at least two ambiguity resolution signals all having different frequencies, said system being of the type wherein the position indicating signals are heterodyned at a fixed point in the system to develop a first difference frequency while the ambiguity resolution signals are similarly heterodyned to develop a second difference frequency and wherein said first and second difference frequencies are respectively used to produce first and second reference signals for radiation from said fixed point, said mobile receiving equipment comprising means for receiving all of said signals to detect the first and second reference signals, to heterodyne the position indicating signals to develop a first beat frequency and to heterodyne the ambiguity resolution signals to develop a second beat frequency, means responsive to the first beat frequency and the first reference signal for providing a first position indication accurately representing the location of the mobile receiving equipment relative to a first set of hyperbolic isophase lines having foci at said spaced points, a lane identification circuit jointly responsive to said second beat frequency and to said second reference signal, phase shifting means operated by the means providing the first indication for phase shifting one of the two last mentioned signals by a first amount which is a function of the position of the mobile receiving equipment relative to said first set of hyperbolic isophase lines, said lane identification circuit including comparison means for comparing the phase of the ouput of the phase shifting means with that of the other of said two last mentioned signals in order to provide an output signal which is nulled when the compared signals bear a predetermined phase relationship, means for phase shifting one of said two last mentioned signals by a second amount of sufficient value to establish said predetermined phase relationship, and means for measuring said second amount to provide a second position indication relative to a second set of hyperbolic lines having foci at said spaced points but spaced farther apart than the first set so that said second position indication is less accurate than said first position indication but is useful in resolving ambiguities of the first indication.

17. The apparatus defined by claim **16** wherein the means for phase shifting by said second amount comprises a servo mechanism operated automatically by said two last mentioned signals.

18. Mobile receiving equipment for use in radio location systems of the hyperbolic, continuous wave type radiating from spaced points at least two position indicating signals and at least two ambiguity resolution signals, said position indicating signals differing from each other in frequency but falling within a first channel, said ambiguity resolution signals also differing from each other but falling within a second channel distinguishable from the first channel, said system being of the type wherein the position indicating signals are heterodyned at a fixed point in the system to develop a first difference frequency while the ambiguity resolution signals are similarly heterodyned to develop a second difference frequency and wherein said first and second difference frequencies are respectively used to produce first and second reference signals modulated upon at least one carrier wave, said mobile receiving equipment comprising means for receiving all of said signals to detect the first and second reference signals, to heterodyne the position indicating signals to develop a first beat frequency and to heterodyne the ambiguity resolution signals to develop a second beat frequency, means for comparing the phase of the first beat frequency with that of the first reference signal to develop a first position indication accurately representing the location of the mobile receiving equipment relative to a first set of hyperbolic isophase lines having foci at said spaced points, phase comparison means jointly responsive to said second beat frequency and to said second reference signal, phase shifting means operated by said comparing means for introducing into one of the two last mentioned signals a phase shift which is a function of the position of the mobile receiving equipment relative to said first set of hyperbolic isophase lines, said phase comparison means including means responsive to any phase difference between the output of the phase shifting means and the other of said two last mentioned signals to provide a second position indication relative to a second set of hyperbolic lines having foci at said spaced points but spaced farther apart than the first set so that said second position indication is less accurate than said first position indication but is useful in resolving ambiguities of the first indication, the spacing of the second set of hyperbolic lines being a function of the frequency difference between the first and second channels.

19. The apparatus defined by claim **18** wherein the means for providing the second position indication includes a servo mechanism operated in response to any phase difference between the output of the phase shifting means and said other last mentioned signal.

20. Mobile receiving equipment for use in radio location systems of the hyperbolic, continuous wave type radiating from spaced points at least two position indicating signals and at least two ambiguity resolution signals all having different frequencies, said system being of the type wherein the position indicating signals are heterodyned at a fixed point in the system to develop a first difference fre-

quency while the ambiguity resolution signals are similarly heterodyned to develop a second difference frequency and wherein said first and second difference frequencies are respectively used to produce first and second reference signals for radiation from said fixed point, said mobile receiving equipment comprising means for receiving all of said signals to detect the first and second reference signals, to heterodyne the position indicating signals to develop a first beat frequency and to heterodyne the ambiguity resolution signals to develop a second beat frequency, means responsive to the phase relationship between the first beat frequency and the first reference signal for providing a first position indication accurately representing the location of the mobile receiving equipment relative to a first set of hyperbolic isophase lines having foci at said spaced points, phase comparison means for comparing the phases of said second beat frequency and said second reference signal to provide a second position indication representing the location of the receiving equipment relative to a second set of hyperbolic lines having foci at said spaced points but spaced farther apart than the first set so that said second position indication is less accurate than said first position indication but is useful in resolving ambiguities of the first indication, and phase shifting means operated by the means providing the first indication for phase shifting one of the two last mentioned signals prior to the comparison by an amount which is a function of the position of the mobile receiving equipment relative to said first set of hyperbolic isophase lines.

21. Mobile receiving equipment for use in radio location systems of the hyperbolic, continuous wave type radiating from spaced points at least two position indicating signals and at least two ambiguity resolution signals all having different frequencies, said system being of the type wherein the position indicating signals are heterodyned at a fixed point in the system to develop a first difference frequency while the ambiguity resolution signals are similarly heterodyned to develop a second difference frequency

and wherein said first and second difference frequencies are respectively used to produce first and second reference signals for radiation from said fixed point, said mobile receiving equipment comprising means for receiving all of said signals to detect the first and second reference signals, to heterodyne the position indicating signals to develop a first beat frequency and to heterodyne the ambiguity resolution signals to develop a second beat frequency, means responsive to the first beat frequency and the first reference signal for providng a first position indication accurately representing the location of the mobile receiving equipment relative to a first set of hyperbolic isophase lines having foci at said spaced points, phase comparison means jointly responsive to said second beat frequency and to said second reference signal, phase shifting means operated by the means providing the first indication for phase shifting one of the two last mentioned signals by an amount which is a function of the position of the mobile receiving equipment relative to said first set of hyperbolic isophase lines, said phase comparison means including means responsive to any phase difference between the output of the phase shifting means and the other of said two last mentioned signals to provide a second position indication relative to a second set of hyperbolic lines having foci at said spaced points but spaced farther apart than the first set so that said second position indication is less accurate than said first position indication but is useful in resolving ambiguities of the first indication.

References Cited by the Examiner

UNITED STATES PATENTS

2,872,676	2/59	Hunsicker	343—105
2,976,530	3/61	Werner et al.	343—117
3,027,556	3/62	Hunsicker et al.	343—105

CHESTER L. JUSTUS, *Primary Examiner.*